GEOLOGICAL SURVEY BRANCH
DEPARTMENT OF MINES AND ENERGY
GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

QUATERNARY GEOLOGY AND GLACIAL DISPERSAL IN THE STRANGE LAKE AREA, LABRADOR

Martin J. Batterson

Report 89-3

St. John's, Newfoundland
1989

Cover

A northward-looking view of a 30-m-high esker ridge within an outwash paleochannel along the southern shore of Strange Lake. This esker contains sediment from the Strange Lake deposit, and in fact, it was in this area that the first mineralized clast associated with the deposit was found. Eskers are prominent features on the Nain Plateau and represent subglacial drainage systems beneath the Laurentide ice sheet.

The fluted till surface of the Nain Plateau is noted to the west of the esker. Individual flutes are commonly subdued, although large crag-and-tail hills are found. These are important features in understanding dispersal patterns from the Strange Lake deposit.

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ABSTRACT

The Strange Lake Zr-Nb-Y-Be-REE deposit, in northern Labrador, is hosted within a peralkaline granite that intrudes Archean and Lower Proterozoic rocks. The deposit has been delineated by diamond drilling. It is, both, geochemically and lithologically different from surrounding rock types, and is therefore an ideal situation for glacial dispersal studies. The down-ice plateau surface and the unidirectional ice-flow recorded over the area favours long-distance glacial transportation.

A total of 1081 glacigenic sediment samples were collected from more than 550 sites over a 1010 km² area. Samples were analysed for 25 elements, by atomic absorption spectrophotometry, X-ray fluorescence or neutron activation techniques. Data is summarized on single element plots, or enhanced through Principal component or Pearson correlation techniques. Clast identification was completed on the 16 to 64 μm fraction.

Analyses of combined sample data from till and outwash or eskers, deflected geochemically or lithologically defined dispersal trains northward, producing erroneous patterns. This clearly shows that consistency of sample media must be maintained in any Quaternary exploration program. Data from any soil horizon developed on till defined a train from the deposit, although individual background geochemical values varied between soil horizons. Again, consistency of sample media must be maintained. The C horizon is preferred because it allows identification of parent material during sample collection, although no statistically significant difference was found in the geochemistry between BC and C horizon samples. Regionally, geochemical variation between mudboils and adjacent C horizon samples is less than 10 percent for Strange Lake deposit-related elements. Values for base metals, Fe and Mn are more variable and are commonly enhanced within mudboils.

Dispersal trains, consistent with flow directions from Late Wisconsinan, Laurentide ice, are ribbon-shaped and extend for at least 40 km. Single element maps for ore-related geochemical components show that the mineralization is best identified by Be, La, Pb, Nb and Y. The deposit is also defined by Ce, Rb, Th, U and Zr but not as clearly. Lithologically distinct phases of the peralkaline granite identified in bedrock are also expressed in the down-ice dispersal of clasts. The peralkaline boulder train can be subdivided into north−south components that mirror the lithological variation across the bedrock source. Well-defined anomalies, within both the geochemical and lithological dispersal trains, are the result of englacial transport within the ice and the interception of these debris-planes by topographic highs.

This study demonstrates the clear usefulness of drift exploration studies in areas of extensive overburden. Examination of dispersal patterns, from deposits of known extent, lead to the development of enhanced exploration techniques, which can be used in the search for the bedrock source of mineralized float and/or geochemical anomalies in other areas.

THE STRANGE LAKE AREA: INTRODUCTION AND BACKGROUND

INTRODUCTION

In Newfoundland and Labrador, and indeed over much of Canada, mineral drift-exploration activity has traditionally outpaced Quaternary mapping. Numerous occurrences of mineralized float and geochemical anomalies in glacial drift have not been traced to their original bedrock sources. This results from a lack of appreciation of the processes of glacial transportation and deposition, and highlights the need for Quaternary mapping surveys, in areas of mineral potential.

The recent discovery of a Zr-Nb-Y-Be-REE deposit by the Iron Ore Company of Canada at Strange Lake[1] has generated much interest. The economic potential of the deposit is considerable, with estimated reserves of at least 57 million short tons (Venkateswaran, 1983), and an average ore grade of 3.25 percent ZrO_2, 0.66 percent Y_2O_3, 0.12 percent BeO, 0.56 percent Nb_2O_5 and 1.3 percent rare-earth oxides (Dawe, 1984). The discovery offers an excellent opportunity to study the effects of glacial dispersion from a deposit, which is unique in terms of its geochemistry and mineralogy and whose components are distinct from the surrounding rock types.

This study of the Strange Lake deposit area focuses on several aspects of glacial dispersion, including the lithology of boulder train(s) and the geochemical signature of the deposit in Quaternary sediments. Also, down-ice dispersion patterns and geochemical trends are documented. This approach provides the opportunity to describe, in detail, glacial dispersion from an exploration standpoint.

LOCATION AND ACCESS

The Strange Lake deposit is situated approximately 145 km west of Nain, Labrador, on the Labrador–Québec border (Figure 1). The study area consists of NTS map sheets 14D/5 and the Labrador portion of 24A/8, an area of approximately 1010 km², lying between 63°30' and 64°10'W and 56°15' and 56°30'N. The area is accessible using helicopter or fixed-wing aircraft; an overland route to the deposit from the coast is being considered should the deposit be developed. The direction of this route is speculative and is more fully discussed by Ricketts (1987).

PHYSIOGRAPHY

The study area has been included in several small-scale terrain classification programs. The area has been characterized as 'high plateau' (Douglas and Drummond, 1955; Lopoukhine *et al.*, 1977), although Lopoukhine *et al.*

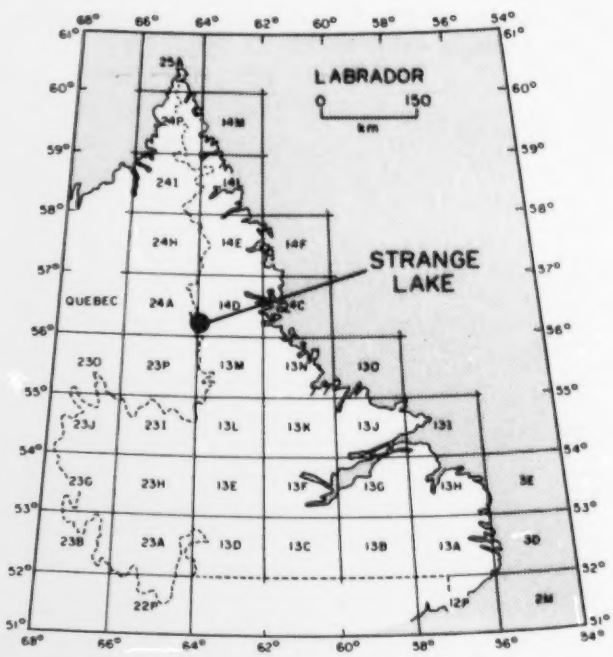


Figure 1. *Index map showing the location of the Strange Lake area, Labrador.*

(1977) refined the description to one of a 'dissected upland' comprising a veneer of till over bedrock, commonly drumlinized, along with small areas of bedrock and colluvium. More recently, the terrain features have been described, in detail, by Batterson *et al.* (1985), and McConnell *et al.* (1984).

The major topographic feature in the Strange Lake vicinity is a peneplain surface (the Nain plateau; Ives, 1960a) that was elevated above the sea during the Pliocene (Cooke, 1929). This plateau has a maximum elevation of 700 m above sea level (a.s.l.) near the coast, and generally decreases in elevation inland. The study area has a mean elevation of 500 m a.s.l., although uplands reach up to 600 m a.s.l.. The Strange Lake area lies on the eastern side of the Atlantic Ocean–Ungava Bay watershed, the boundary between Labrador and Québec. Within the vicinity of the deposit, the watershed occurs in an area of subdued relief and is poorly defined. Efforts are underway to more accurately delineate this boundary, because its resolution will have implications on provincial taxes and royalty payments should a mine be established.

The Nain plateau is dissected by a number of major river valleys in the vicinity of the study area, e.g., the Fraser, Anaktalik, Ikadlivik, Konrad and Kogaluk. Of these, the Fraser River valley is the most extensive, penetrating inland for over 100 km, with the lower 60 km forming the fiord

[1] Strange Lake is an informal name. It is located approximately 15 km northeast of Lac Brisson, Québec.

Tasisuak Lake (Plate 1). Valley sidewalls throughout the fiord attain heights of 450 to 500 m.

Plate 1. *Panoramic view looking east along the Fraser River valley with fiord Tasisuak Lake in the background. The valley sidewalls are commonly 400 m high. The valley was a major outlet for glacial ice, during the Late Wisconsinan.*

CLIMATE

The Strange Lake area has been classified within an 'Interior Labrador' climatic zone (Banfield, 1981). This climatic zone covers all of south and west interior Labrador, and spreads north to approximately the Fraser River valley, north of which a 'Northern Labrador' climatic zone is defined. It is likely that the Strange Lake area, on the high Nain plateau, exhibits characteristics of both climatic zones and therefore has a continental climatic regime.

Permanent weather stations are not located in the vicinity of the study area. The nearest station, at Nain, is situated at sea level and therefore does not reflect climatic conditions on the Nain plateau. Climatological data is interpolated from existing regional stations, and may therefore not accurately characterize the climate conditions at Strange Lake. Nevertheless, winters are long and severe, with heavy snowfall of up to 350 cm/yr, and extended periods of temperatures below -15°C (Banfield, 1981). The mean annual temperature is -5°C (Peach, 1975) and the mean temperature for February is estimated to be -22°C. The summers are short and cool and mean July temperatures may be 11°C (or less), although occasionally temperatures have exceeded 20°C. Annual precipitation ranges between 900 and 1100 mm with a summer maximum. The exposure and lack of vegetation in the area often contributes to strong winds that generally have a westerly direction.

The climatic conditions in the Strange Lake area have several important implications. Firstly, mean annual temperatures fall within the range expected for discontinuous permafrost, and secondly, the mean temperature of the warmest months is about 10°C, the lower limit for continuous tree coverage. This explains the lack of trees over most of the area, except in small, sheltered valleys or enclaves where mean temperatures may be higher.

SOILS, VEGETATION AND PALEOENVIRONMENTAL CONDITIONS

The Strange Lake area lies above the present tree line. Current vegetation is sparsely distributed and is classified as 'Low Arctic Tundra' (Rowe, 1972). The modern pollen spectrum is composed of ericaceous shrubs and herbs, typical of pioneer, tundra or heathland vegetation [willow (*Salix*), sedges (*Cyperaceae*), grasses (*Gramineae*), other herbs and heaths (*Ericales*)], and taller shrubs and club-mosses [alder (*Alnus*), sweet gale (*Myrica gale*), juniper (*Juniperus*) and some *Betula*] (Macpherson, 1981).

Pollen diagrams are available from Kogaluk Plateau Lake (Short, 1978), located 50 km south of the study area, within the same physiographic and climatic unit. Based on a radiocarbon date of 8610 ± 925 BP (SI-1955) from basal sediment, Kogaluk Plateau Lake became ice free sometime before 9500 BP, and interpretation of pollen reveals a shrub–tundra–birch vegetation assemblage. Subsequent climatic changes resulted in vegetation changes to a predominantly shrub–birch assemblage with associated minor tundra-type vegetation and boreal vegetation by 6000 BP, and a return to a shrub–birch assemblage by 5000 BP Boreal trees became more dominant at the expense of both the shrub and birch types by 4000 BP, with a slight re-emergence of tundra vegetation by 2000 BP.

Vegetation successions are largely due to climatic fluctuations, and through analysis of pollen data, Holocene climatic changes are inferred (Macpherson, 1981). Similarly, rates of organic sedimentation within the Labrador lakes are interpreted as indicative of changing climatic conditions because they reflect lacustrine organic productivity. Palynological studies suggest that sedimentation rates were generally higher in immediate postglacial times than they are today (Figure 2). Sedimentation rates increased, in association with an ameliorating climate, until a climatic optimum was reached between 4500 and 3000 BP. This period also corresponds to an increase in the ambient moisture and an increase in organic productivity. Following this climatic optimum, conditions steadily changed to those of today. This resulted in falling treelines (Short, 1978), and also explains the thin boreal forest remnants in the Strange Lake area.

The onset of warmer conditions following deglaciation was much later in northern Labrador than in southern Labrador (Macpherson, 1981). This may be related to the presence of remnant glacier-ice inland and the discharge of large amounts of glacial meltwater into Hudson Bay and its subsequent injection into the Labrador Current (Macpherson, 1981). The resultant climatic circulation pattern would deflect cyclone activity southward, and essentially block the influx

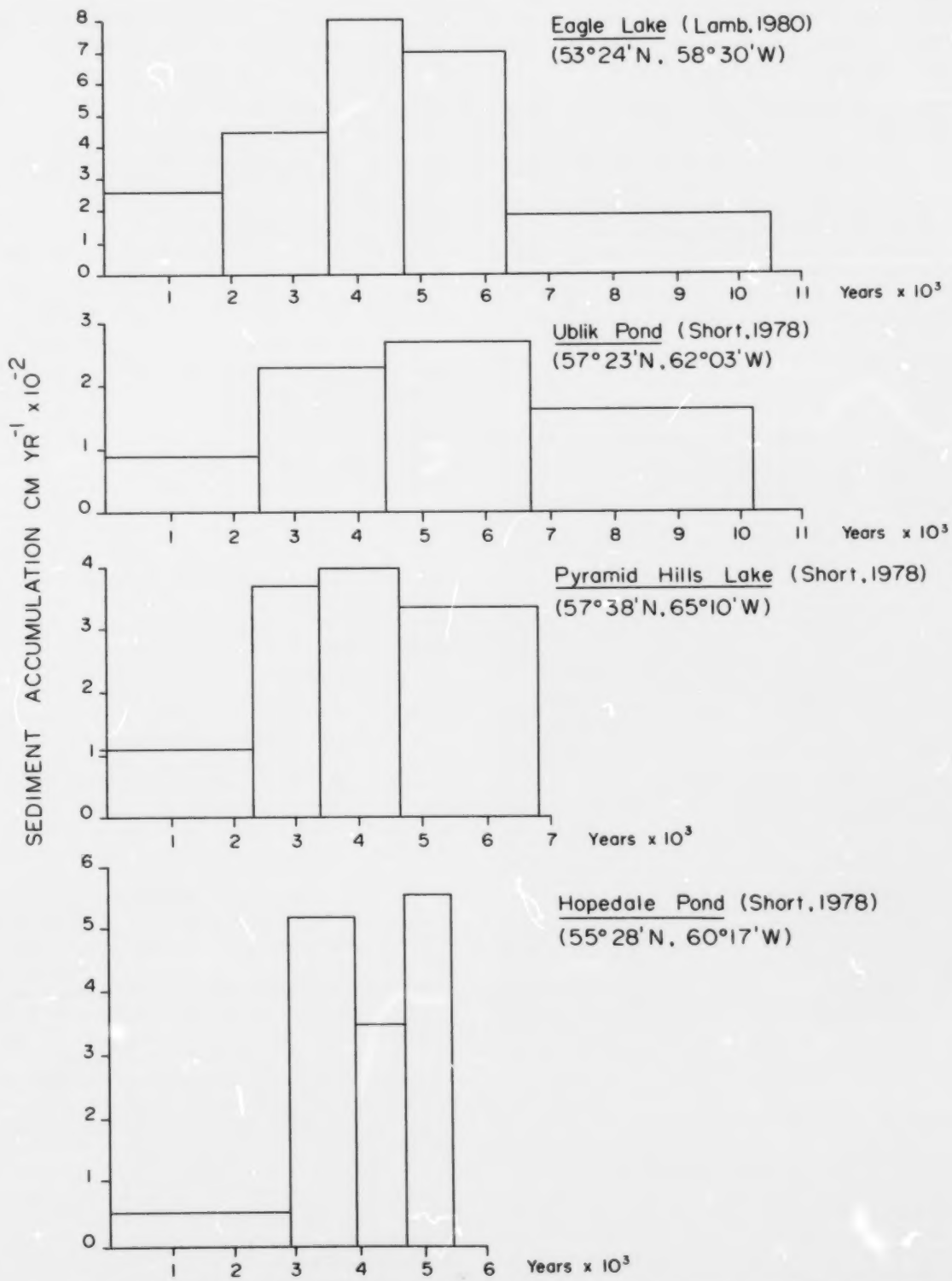


Figure 2. *Histograms showing the estimated sedimentation rates, for the last 11,000 years, from four selected ponds and lakes in Labrador (after Short, 1978; Lamb, 1980).*

of moist, warm air into northern latitudes. Final deglaciation allowed warmer air to penetrate northward and led to a period of rapid climatic amelioration (Macpherson, 1981).

The harsh climate and sparse vegetation have resulted in poorly developed modern soils. Although the type and degree of pedogenesis varies across the study area, particularly in response to drainage, the typical soil in moderately and better drained areas has a profile composed of a thin (approximately 1 cm) surface organic matter accumulation, probably of the Mor type; a thin (1 to 8 cm), dark grey, structureless, sandy, A horizon; a thin (1 to 3 cm), light grey, structureless, sandy, friable, Ae horizon; a moderately to well developed, 10- to 25-cm thick, brown to dark brown, firm sandy loam, B horizon; and an underlying transitional BC horizon, 10- to 50-cm thick, tan brown, sandy loam, that commonly has the same morphological characteristics as the parent material (Plate 2).

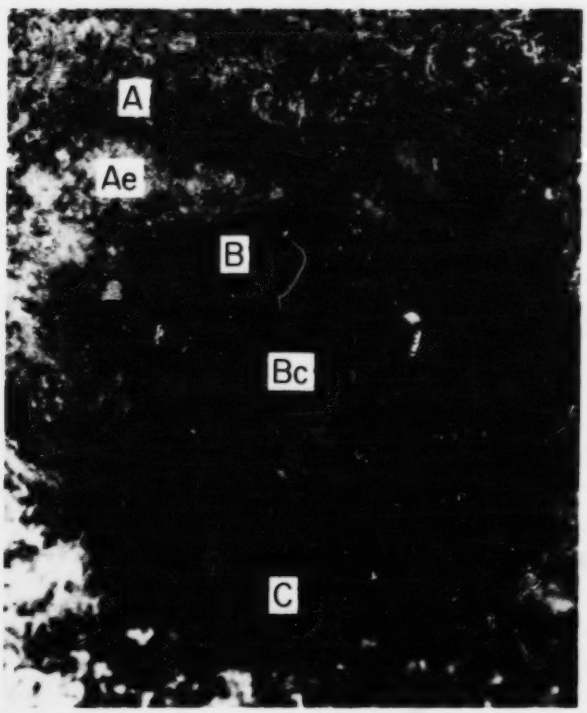


Plate 2. *Typical soil profile of the Podzolic order in the Strange Lake area (see text for details).*

These morphological characteristics are consistent with soils of the Podzolic order (Canada Soil Survey Committee, 1978). However, the possibility remains that the profile may represent a Luvisol or Brunisol, a possibility that cannot be rejected without detailed descriptions and chemical analyses. Nevertheless, the morphology, climatic regime and vegetation under which the soil profile has developed, strongly suggests a podzolic development.

Although not observed, two other soil orders may be expected. In the poorly drained lowland areas, development of a gleysol or humic gleysol is likely, whereas in areas of thin overburden, especially where exposed on hilltops, soils of the Regosolic order are probable.

GLACIAL HISTORY

Evidence from numerous sources, both terrestrial and marine, suggests a complex series of glaciations during the Quaternary for most of northeastern North America (e.g., Denton and Hughes, 1981; John, 1979). In the Strange Lake area, however, only evidence of Late Wisconsinan glaciation is found. This was the last major phase of glacial activity in northern Labrador.

There had been no previous Quaternary research in the Strange Lake area prior to the discovery of the deposit. However, studies have been done on the glaciation and deglaciation of the George River valley to the west (e.g., Barnett and Peterson, 1964), and on the development of weathering zones and deglaciation in the coastal areas around Nain (e.g., Ives, 1978).

The Laurentide ice sheet is considered to have developed through 'instantaneous glacierization' of upland surfaces as a result of climatic deterioration (Ives, 1957; Ives *et al.*, 1976). Year-round snow on the uplands would alter climatic circulation patterns, leading to a lowering of the snowline and a rapid build-up of glacier ice. Ice-flow patterns reveal an essentially radial flow pattern related to an ice dome (or domes) and associated ice divides, located to the east of Hudson Bay (Shilts *et al.*, 1979; Shilts, 1980; Hillaire-Marcel *et al.*, 1980; Dyke and Prest, 1987) (Figure 3). Flow was not topographically controlled in the high plateau areas, as confirmed by the oblique orientation of lineated till features across major river valleys, which were probably filled with inactive ice (Ives, 1960b). The Strange Lake area was completely covered by ice during the Late Wisconsinan.

The lack of recessional moraines and the widespread presence of glaciofluvial features suggest deglaciation probably occurred by downwasting rather than a recessional process, exposing the coastal highlands first (Ives, 1960b). Deglaciation commenced about 10,500 BP on the Labrador coast (Short, 1978) and progressed in a southwesterly direction. As the Laurentide ice sheet receded over the Atlantic–Ungava Bay watershed, a succession of proglacial lakes developed, ponded between inland ice situated over Ungava Bay to the north, and the Labrador–Ungava plateau to the west and south, and the highlands to the east (Ives, 1960a).

The proglacial lake system is named Lake Naskaupi-McLean (Ives, 1960a), although the two lakes were only united during the initial stages of development. This area has been a focus of research by the McGill Subarctic Research Laboratory (Barnett and Peterson, 1964; Ives, 1960a,b; Ives *et al.*, 1976). Radiocarbon dates from basal lake sediments record initial lake development postdating 8700 BP and provide an approximate date for deglaciation of the Strange

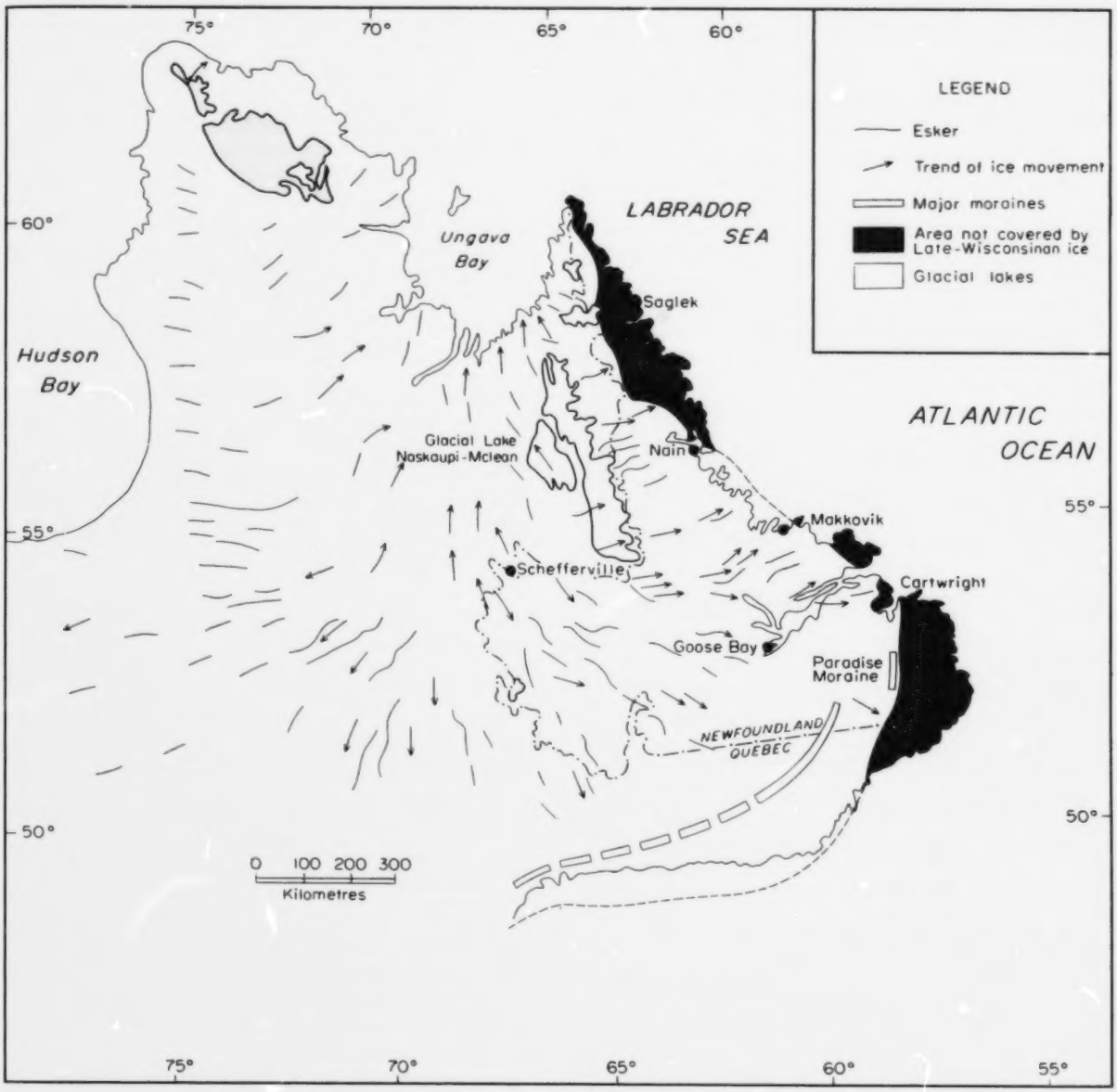
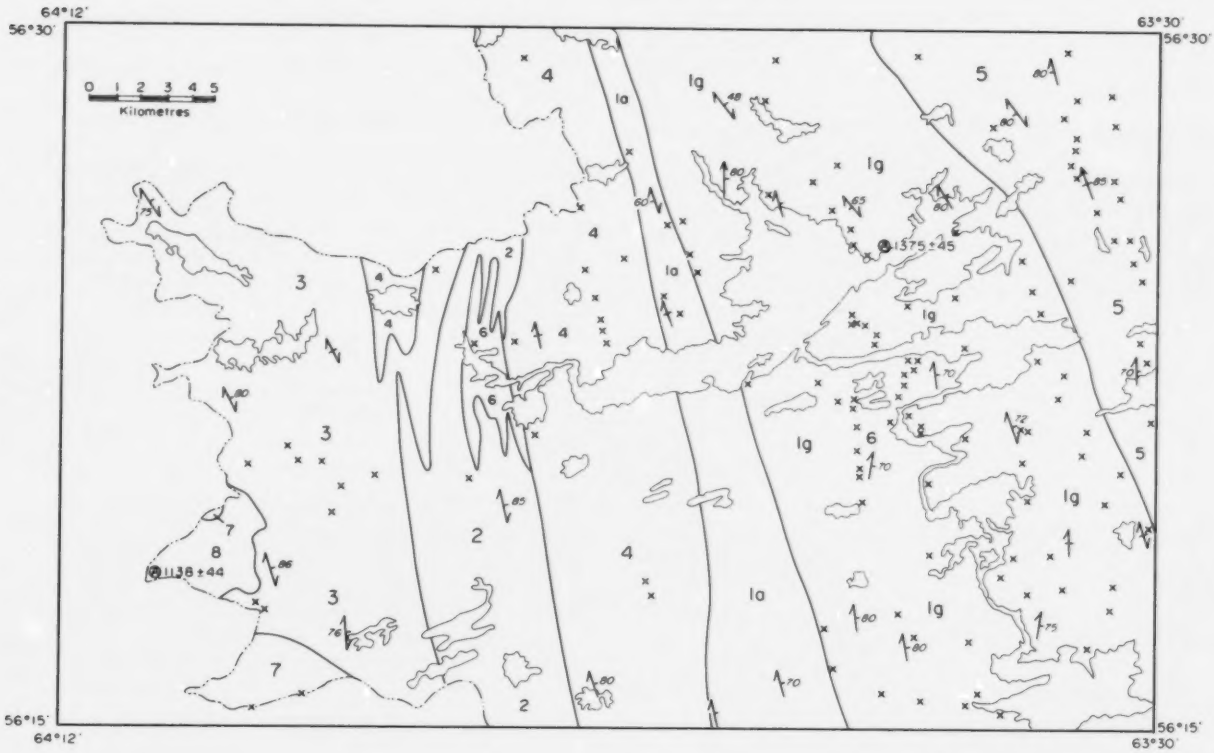


Figure 3. *Late Wisconsinan ice-flow patterns on the Labrador peninsula.*

Lake area. Analysis of shorelines, related to Naskaupi 2 (the largest of three known lakes), reveals that shorelines are tilted to the southwest (Barnett and Peterson, 1964), which provides additional evidence that the Labrador–Ungava peninsula was a major ice-dispersal centre. Eventual drainage of Lake Naskaupi occurred as successively lower outflow channels were exposed, primarily through the Kogaluk River system (Barnett and Peterson, 1964), with lesser discharge routes via the Fraser River and other more southerly outlets (Prest et al., 1968). The Strange Lake area was unaffected by major drainage from Lake Naskaupi, although the elevation and position of the area relative to Lake Naskaupi suggests some outfow was likely.

BEDROCK GEOLOGY OF THE STRANGE LAKE AREA

Apart from studies of the peralkaline granite complex, which hosts the Strange Lake mineral deposit, the field area has been the focus of reconnaissance level geological mapping (Taylor, 1970, 1979), and more recent detailed mapping (Ryan *et al.*, 1988). The geology consists of Archean and Lower Proterozoic (Aphebian) migmatites and associated rocks, which are intruded by younger Middle Proterozoic (Paleohelikian) adamellites in the east-central part of the map area. Subsequent mapping has redefined the intrusive body



LEGEND

MIDDLE PROTEROZOIC

- 8 *Strange Lake peralkaline granite*
- 7 *Adamellite (Rapakivi granite)*

ARCHEAN AND LOWER PROTEROZOIC

- 6 *Biotite granite*
- 5 *Mylonitized gneiss – granulite facies*
- 4 *Pegmatoidal white granitic gneiss*
- 3 *Gabbronorite gneiss*
- 2 *Biotite-rich gneiss and augen gneiss*
- 1 *Quartzofeldspathic migmatite: 1g = granulite facies; 1a = amphibolite facies*

SYMBOLS

- *Foliation (inclined, vertical)*
- *Bedding and primary igneous layering (inclined, vertical)*
- *Bedrock outcrop*
- *Geological boundary (approximate)*
- *Provincial boundary*
- *Isotopic age (million of years)* Ⓐ

Figure 4. *Bedrock geology of the Strange Lake area (adapted from Ryan* et al., *1988).*

as hosting the Strange Lake deposit (Zajac *et al.*, 1984). An attempt was also made to subdivide the migmatitic group into discrete units to determine any rock type–landform relationships. These descriptions are generally consistent with those of Ryan *et al.*, (1988), and the geological compilation map (Figure 4) is based mainly on their work. The following rock units have been identified.

Gneissic Rocks (Units 1–5)

Gneisses underly most of the study area. They have been described by Taylor (1970, 1979) as Archean and Lower Proterozoic migmatites and mainly comprise of amphibolite and metasedimentary (paragneiss) rocks mixed with granulites. In this report, more specific compositional

terminology is used in characterizing gneissic rocks because it permits correlation with more detailed mapping, and it avoids confusing and awkward nomenclature.

In the eastern part of the study area, migmatite gneisses occur in a broad north–south-trending belt . This unit varies from grey weathering (amphibolite facies; subunit 1a) to buff- and yellow-brown weathering (granulite facies; subunit 1g) rocks (Ryan *et al.*, 1988). To the east, the granulite facies gneisses have been intensely mylonitized (Unit 5). A dark-grey weathering, medium grained, biotite- and hornblende-rich quartzofeldspathic gneiss (Unit 2) outcrops to the west of Strange Lake (Ryan *et al.*, 1988). This unit commonly contains quartz or feldspar augens that range in colour from white to pinkish-red. It is bounded on the west by a fine- to medium-grained, equigranular, gabbro-norite gneiss (Unit 3) and to the east by a white, pegmatoidal granite gneiss (Unit 4). This latter unit is significant due to its local radioactive zones, which produce a clear signature on airborne gamma-ray spectrometer maps (Geological Survey of Canada, 1986) and allows delineation of the unit through drift-covered areas. Units 4 and 5 comprise the uplands and Units 1, 2 and 3, the areas of low relief within the gneissic terrane.

The gneisses of Units 1 to 5 are generally well foliated and have a regional north–south strike, dipping to the west (Taylor, 1979; Hlava and Krishnan, 1980). Veins or lenses of quartz, commonly with a bluish hue, are common and concordant with the gneiss. Larger quartzose veins associated with garnets also occur. Within the gneisses, small plutons of diorite and diabase (Hlava and Krishnan, 1980) have been identified, although not as mappable units. The similarity of rock types means that these units cannot be used for provenance and dispersal studies.

Biotite Granite (Unit 6)

This rock type is exposed at the western end of Strange Lake and elsewhere as small isolated plutons. The granite is massive to weakly foliated, white to pink, equigranular and fine grained (Ryan *et al.*, 1988).

Adamellite (Rapakivi Granite) (Unit 7)

Two areas of adamellite were mapped, both outcropping along the Labrador–Québec border. The adamellite is coarse grained, reddish brown where weathered, and pinkish grey where fresh. It is composed of quartz, orthoclase, plagioclase, biotite and hornblende, plus other mafics (probably clinopyroxene, hypersthene and olivine). The adamellite is deeply weathered and Taylor (1970) describes some areas as having over 3 m of weathered bedrock. In the Strange Lake area, the weathering is related to the adamellite grain size. Glacially transported adamellite boulders are also highly weathered, suggesting that the weathering is postglacial and rapid.

Adamellite boulders are useful indicators of glacial transport distances and direction because they are easily identifiable and confined to the western margin of the field area.

Strange Lake Peralkaline Granite (Unit 8)

The Strange Lake deposit is hosted within a 1271 ± 30 Ma (Zajac *et al.*, 1984) peralkaline granite intrusion, having an irregular ovoid (8 by 6 km) surface expression, occupying a surface area of about 32 km². The margins of the Strange Lake peralkaline granite are delineated by a ring fault, which is a prominent fluorite and fluorite–hematite bearing breccia zone dipping toward the northwest at about 20 to 35° (Zajac *et al.*, 1984). Mineralogically, the Strange Lake peralkaline granite is made up of quartz, feldspar (albite + K-feldspar, or microperthite), riebeckite and aegerine. The Strange Lake deposit is 'strange' because it contains some rare and currently unnamed minerals and is enriched in many incompatible elements (Miller, 1986). These 'exotic' minerals and their associated ore elements include elpidite (Na–Zr silicate), and gittinsite (Ca–Zr silicate) plus pyrochlore (Nb, Ta), armstrongite (Zr), gadolinite (Y, Be), kainosite (Y), fluorite, allanite (Ce, Y), sphene, zircon, thorite and narsarsukite [(Na-Ti), Fe silicate] (Zajac *et al.*, 1984; Currie, 1985; Miller, 1986). A complete list of these minerals and their physical characteristics is given in Table 1.

On the basis of the relative proportions of these 'exotic' minerals, Miller (1986) has subdivided the complex into three discrete units (Figure 5). The exotic-poor phase contains less than 5 percent 'exotic' minerals and comprises about 70 percent of the complex, predominantly the outer margins; the exotic phase contains 5 to 10 percent and locally up to 15 percent 'exotic' minerals and occupies the central part of the complex; and the exotic-rich phase contains greater than 10 percent exotic minerals and has the highest grade mineralization. The exotic-rich phase is the smallest unit in area (approximately 1 km²) but contains up to 2.4 percent ZrO_2, 3.3 percent Y_2O_3, 0.9 percent Nb_2O_5, 1.5 percent BeO and 2.6 percent total REE. These major groups can also be subdivided on the basis of grain size, and the presence or absence of inclusions. The major- and trace-element geochemistry of the Strange Lake peralkaline granite and other rock types in the area is presented in Table 2.

THE QUATERNARY GEOLOGY OF THE STRANGE LAKE AREA

GLACIAL EROSIONAL FEATURES

This study shows that the Laurentide ice sheet covered the study area during the Late Wisconsinan sub-stage, and there is depositional and erosional evidence for this event, which is presented here. Glacial erosional features are indicators of former ice-flow directions, although, here, the lack of rock outcrop, make these features relatively uncommon. However, two major types of erosional features are present.

Table 1. Physical characteristics of minerals within the Strange Lake deposit

Mineral	General Formula	System	Specific Gravity	Hardness	Cleavage	Tenacity	Fracture	Colour	Lustre
Aenigmatite	$Na_2Fe_5^{+2}TiSi_6O_{20}$	Triclinic	3.8	5.5	Perfect {010} {100}			Black	
Allanite	$(Ca,Ce)_2(Fe^{+2},Fe^{+3})Al_2O.OH[Si_2O_7][SiO_4]$	Monoclinic	3.4-4.2	5-6.5	Absent	Brittle	Conchoidal	Light brown black	Resinous
Armstrongite	$CaZrSi_6O_{15}.2.5H_2O$	Monoclinic	2.7						
Astrophyllite	$(K,Na)_3(Fe,Mn)_7Ti_2[Si_4O_{12}]_2(O,OH,F)_7$	Triclinic	3.3-3.4	3.5	Perfect {001}			Bronze	
Elpidite	$Na_2Zr(Si_6O_{15}).3H_2O$	Monoclinic	2.5-2.6	5	Distinct {110}		Splintery	White	Silky vitreous
Fluorite	CaF_2	Cubic	3-3.25	4	Perfect	Brittle	Conchoidal	Blue, white, yellow	Vitreous
Gadolinite	$Y_2FeBe_2[SiO_4]_2O_2$	Monoclinic	4-4.7	6.5-7	Absent		Conchoidal	Black	Vitreous
Gagarinite	$Na(Y,Ca,Na)_2F_6$	Hexagonal	4.2	4.6	Distinct prismatic			Pinkish	Dull
Galena	PbS	Cubic	7.5	2.5	Perfect cubic		Even	Lead grey	Dull
Gittinsite	$CaZrSi_2O_7$		3.6	3.5-4				White	
Kainosite	$Y_2Ca_2Si_4O_{12}CO_3.H_2O$	Orthorhombic	3.3-3.6	5-6	Unidirectional		Uneven	Yellowish brown	Vitreous
Monazite	$(Ce,La,Th)PO_4$	Monoclinic	5-5.3	5	Moderate {100} Perfect {001}	Brittle	Uneven	Yellow reddish brown	Resinous
Narsarsukite	$Na_2(Ti,Fe)Si_4O_{10}(OH,F)$	Tetragonal	2.8	7-7.5	Perfect			Yellowish	
Pyrochlore	$(Na,Ca)(Ta,Nb)_2O_6.(O,OH,F)$	Cubic	4-4.3	5-5.5	Rare	Brittle	Uneven to conchoidal	Reddish brown	Resinous
Sphene	$CaTi[SiO_4](O,OH,F)$	Monoclinic	3.5-3.6	5	Good {110}	Brittle	Imperfect conchoidal	Brown, green, yellow	Resinous
Thorite	$ThSiO_4$	Tetragonal	5.3	5	Poor		Conchoidal	Reddish brown to black	Resinous
Vlasovite	$Na_2ZrSi_4O_{11}$	Monoclinic	3.0	6	Perfect {010}	Brittle		Colourless	Vitreous
Zircon	$ZrSiO_4$	Tetragonal	4.7	7.5	Poor		Conchoidal	Colourless, greenish, reddish brown	Adamantine

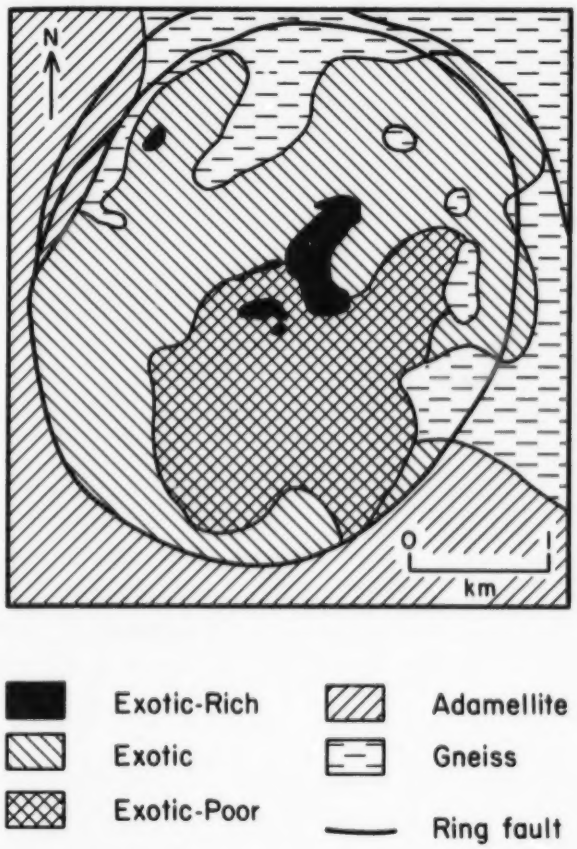


Figure 5. *Generalized bedrock geology of the Strange Lake peralkaline granite (after Miller, 1986).*

Roches Moutonées

These features are oriented parallel to glacial flow, and have a pronounced asymmetric profile (Plate 3). They are usually less than 3 m in height and are formed through abrasion on the up-glacier side, and plucking by freeze-thaw within a cavity on the down-glacier side (Sugden and John, 1976). Roches moutonées occur over the entire study area and provide a clear indication of the subglacial environment. In the Strange Lake area, roches moutonées are oriented between 060 and 070°, trending more northward in the east compared to the west. Variations of striae directions around roches moutonées indicate that ice was moulded around the outcrops and this reflects plastic flow conditions at the base of the ice.

Striations

Striations are linear abrasions that are made on exposed bedrock/clast surfaces by debris transported at the base of the ice. They are good indicators of glacial-flow direction because they form parallel to the ice flow. The effectiveness of abrasion is dependent on the presence and the continued supply of debris to the glacier bed plus actively sliding basal ice. Ice thickness, particle and bedrock characteristics, and the presence of basal water, are also important factors in affecting the rate and type of abrasion (Sugden and John, 1976).

In the Strange Lake area, striae have three distinct forms (scratches, nail-heads and grooves) that occur at micro- and macro-scales. Micro features (< 2 cm in length, by 0.2 cm in depth and width) are non-directional striae and directional 'nail-head striae', with their heads located in the down-ice direction. They are relatively rare, except on fine grained xenoliths, because the medium- to coarse-grained nature of the bedrock is not conducive to the preservation of striae. More common are macro scale grooves (20- to 100-cm long by 5- to 20-cm wide and 0.5- to 3-cm deep). The trend of grooves is consistent with striae, commonly cutting across the structural grain of bedrock on which they are found. In places, micro-scale striae occur within the grooves. Only one ice-flow direction has been found in the field area. Deflection of ice around bedrock outcrops is shown by diverging and converging striae on the up-ice and down-ice sides of outcrops respectively.

SEDIMENT TYPES

The glacial depositional environment is characterized by constructional landforms (e.g., flutes, crag-and-tail hills, eskers) and consist of glacigenic diamicton and gravel (Figure 6). Initially, the types of glacigenic and post-glacial material will be described, and this will be followed by discussion of their relationship with landforms.

Diamicton

Three types of diamicton are identified in the vicinity of Strange Lake:

Type I. This sediment type is a thin (50 to 60 cm), massive, over-consolidated diamicton having a silty to fine sandy matrix, and striated clasts of predominantly local origin. Anomalous Strange Lake deposit-related element values and radiometric levels (Figure 7) that are considerably higher than the overlying sediment, correspond to the mineralized bedrock which it directly overlies, and is suggestive of a local origin for this material. Together, these characteristics suggest a subglacial (lodgement ?) genesis (Table 3) i.e., deposited from the sliding base of a dynamically active glacier by pressure melting and/or other mechanical processes (Ashley *et al.*, 1985). This unit was identified in the trench excavated by the Iron Ore Company of Canada (Plate 4) to expose exotic-rich bedrock.

Type II. This sediment type is a normally consolidated diamicton that has a sandy to silty matrix. It contains thin (less than 2 to 3 cm), well-sorted lenses of fine or medium sand. Irregularly shaped inclusions (2 to 3 mm diameter) of pink sand (possibly related to the peralkaline granites) are also found. This unit lies stratigraphically above sediment Type I in one locality and is common throughout the field area. Distinct geochemical and radioactive breaks occur

Table 2: Major- and trace-element geochemistry of Strange Lake deposit and other rock types in the Strange Lake area

	Peralkaline Granite				Gneiss
	Exotic-poor[1] (n=61)	Exotic[1] (n=22)	Exotic-rich[1] (n=14)	Adamellite[2] (n=4)	Complex[2] (n=4)
Major- and minor-element oxides (weight percent)					
SiO_2	70.65	71.45	67.35	72.15	61.75
Al_2O_3	11.70	9.02	8.32	13.15	14.80
Fe	2.02	3.70	3.01	0.80	0.70
FeO	2.47	1.67	1.21	1.15	4.80
MgO	0.04	0.20	0.38	0.36	3.29
CaO	0.69	1.46	4.42	1.39	5.85
Na_2O	5.12	4.25	3.41	2.80	3.15
K_2O	4.70	4.07	4.04	5.57	1.69
TiO_2	0.23	0.34	0.39	0.28	0.54
MnO	0.10	0.15	0.15	0.03	0.10
P_2O_5	0.02	0.03	0.07	0.08	0.12
LOI	0.47	0.57	1.45		
Trace element (g/t)					
Ag	0.0	0.1	0.1	ND	ND
Ba	53	53	183	975	425
Be	36	108	180	ND to 16	ND to 38
Ce	508	958	1011	125	70
Cr	0	0	0	ND to 9	51
Cu	5	8	9	14	30
F	4000	3800	12900	NA	NA
Ga	51	53	52	NA	NA
La	308	691	560	115	50
Li	272	224	268	NA	NA
Mo	3	2	3	NA	NA
Nb	419	909	2027	NA	NA
Ni	0	0	0	NA	NA
Pb	157	270	526	NA	NA
Rb	685	959	852	190	65
Sn	21	60	150	NA	NA
Sr	22	66	211	200	415
Th	88	164	552	NA	NA
U	18.3	37.2	100.3	NA	NA
V	0	0	0	28	102
Y	708	1337	5267	24	ND
Zn	467	948	1062	75	65
Zr	3701	9919	14952	350	195

[1] From Miller (1989, personal communication)
[2] From Currie (1985) NA = Not analyzed ND = Not detected.

between this unit and the underlying one (Figure 7). Strange Lake deposit-related element values (Figure 7) and the radioactive response are lower than the underlying unit, and suggest that this unit contains a higher proportion of far-travelled clasts and matrix than the underlying unit. Within the Iron Ore Company of Canada trench, up to 3 m of Type II sediment are exposed.

The characteristics of this sediment are consistent with those of a subglacial melt-out till (Table 3) i.e., a till formed by the slow release of debris from glacier ice that is not sliding or deforming internally (Ashley *et al.*, 1985).

Type III. This sediment consists of boulders and clasts that are angular to sub-angular and are not striated. In all cases,

Plate 3. *Roches Moutonée at Strange Lake. Ice flow was from left to right.*

they directly overlie sediment Type II. These boulder concentrations occur in close association with areas of glaciofluvial sediment in the southern, central and northern parts of the field area. The boulders in the south-central area are distal in origin, whereas those in the north are all of local origin. This is the highest stratigraphic unit and may be supraglacial in origin.

Glaciofluvial Sediments

The focus of the study in the Strange Lake area is on dispersal patterns in till, and therefore only a brief examination has been made of the glaciofluvial deposits. Outwash is restricted to a series of paleochannels in the southern, central and northern parts of the area. Material in these channels is a veneer of dominantly sand-sized material overlying bedrock or diamicton and distinct gravelly esker ridges (Plate 5). The outwash channels are wide (commonly greater than 2 km) and contain numerous areas of bedrock, kettleholes, and hummocks comprising melt-out till covered by a veneer of boulders (Plate 6). Hummocks may represent the discharge of (frozen?) blocks of diamicton from the downwasting ice sheet and their subsequent melting-out within the outwash system.

Organic

Organic sedimentation has occurred in the Holocene and is common across the area. Organic sediments reflect poorly drained terrain and commonly form a veneer over till. The organic veneer is found at all elevations and is not restricted to low lying areas.

Lacustrine

Minor areas of fine grained sediments related to postglacial wave reworking of primarily outwash sediments were observed around Strange Lake and other lakes in the area, although generally not as mappable units.

OVERBURDEN THICKNESS

Overburden thicknesses data were calculated from drill logs, contained within Iron Ore Company of Canada assessment reports, covering a claim area of about 35.6 km. The maximum recorded overburden thickness within this area is 18.6 m, having an average of between 4 and 6 m (Figure 8).

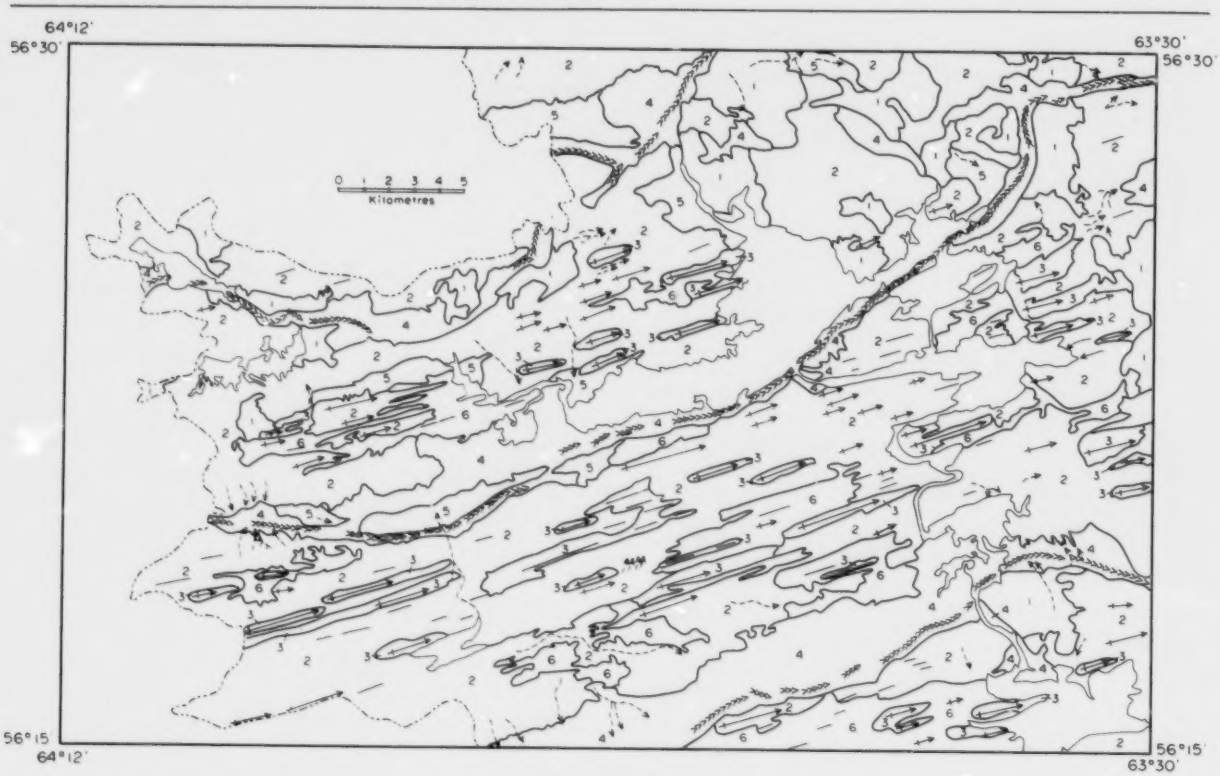
Quantitative data is not available on overburden thickness outside the Iron Ore Company of Canada's claim areas. Thin overburden was noted within some of the outwash channels and in the proximity of bedrock crags. Areas of thicker drift are expected in till tails, which reach heights of 30 m down-ice of bedrock crags. Overburden cover, which decreases in thickness in the northeastern quadrant of the field area, mainly consists of a concentration of locally derived diamicton overlying bedrock. The reason for the thinner drift in the area is unclear but may relate to its topographic setting up-ice of an upland. The consequent compressive flow regime may have resulted in continued erosion, with deposition only occurring during deglaciation.

GEOMORPHOLOGY

The Strange Lake area is dominated by several glacigenic features.

Crag-and-Tail Hills

These are streamlined landforms with a complex depositional history. They are elongate hills, having a steep, narrow, up-ice side and a gentle, long, down-ice profile. The crest is commonly associated with a bedrock knob called the crag. Crag-and-tail hills are common features in the Strange Lake area (Figure 6). The dimensions of these features vary considerably, ranging from small-scale features 5-m high and 100-m long, to large 50-m high and 4-km long hills. No



LEGEND

6 Bog: *Holocene organic sediments; commonly thin veneer (< 1.5 m) overlying till; found at all elevations, in poorly drained areas*

5 Glaciofluvial sediments – Veneer: *Thin (< 1.5 m) covering of well-sorted, medium- to coarse-grained sand over till or bedrock; well drained; commonly occurs along margins of paleochannels*

4 Glaciofluvial sediments – Channel fill: *Well-sorted, medium- to coarse-grained sands and associated gravel; well drained; contained within large (commonly greater than 2-km wide) paleochannels; gravel commonly within esker ridges, 10- to 30-m high and 50- to 200-m wide; eskers commonly found along southern margin of paleochannels*

3 Till with lineated surface: *Commonly a melt-out till having a sandy to silty matrix; contains fine- to medium-sand lenses; clasts subrounded and striated; sediment expressed as linear ridges, up to 50-m high and 4-km long; ridges either flutes with little surface relief, or more commonly as crag-and-tail hills with bedrock exposed at summit, and till comprising the up-ice and down-ice portions*

2 Till: *Undifferentiated till surface; sediment type similar to that described in Unit 3; surface commonly dissected by meltwater channels, expressionless or covered by a veneer of organic sediment*

1 Bedrock: *Either exposed or concealed by vegetation; topography variable; commonly associated with high ground, although patches are found within outwash channels (not as mappable units)*

SYMBOLS

Ridge parallel to flow (flute).....

Crag-and-tail hill.....

Esker.....

Meltwater channel.....

Figure 6. *Map showing the surficial geology of the Strange Lake study area.*

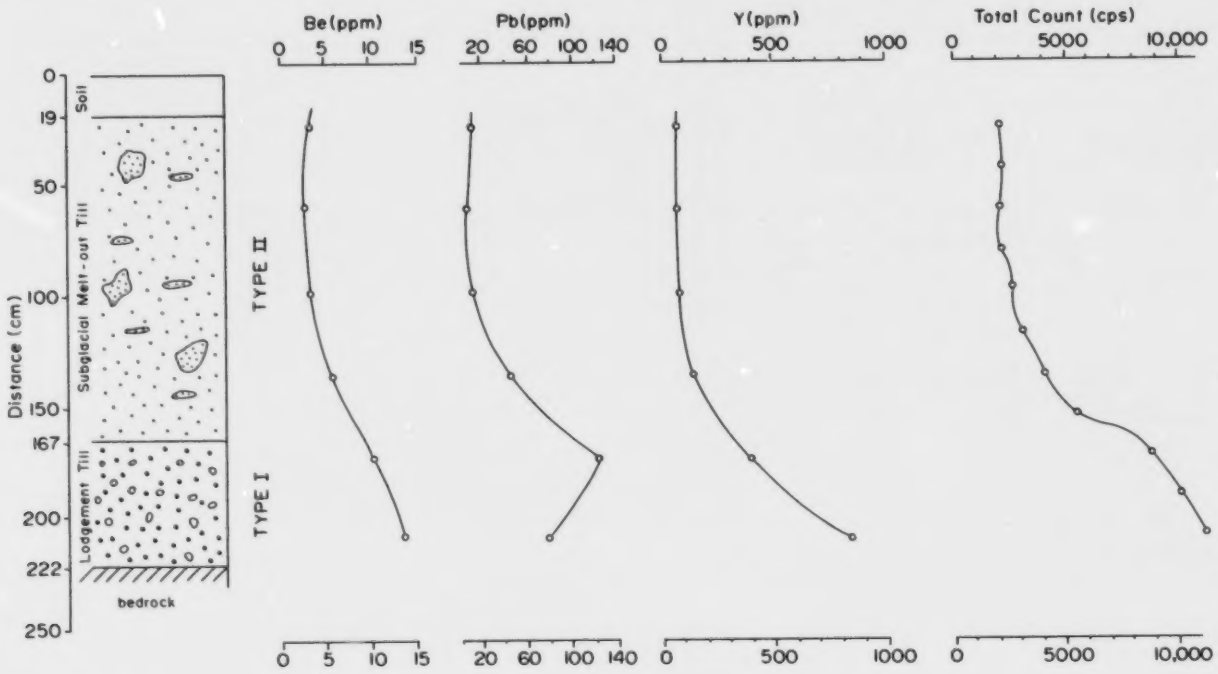


Figure 7. *Geochemical and radiometric characteristics of sediment within the Iron Ore Company of Canada trench at the Strange Lake deposit.*

sections exist through the crag-and-tail hills and therefore the internal structure is unknown. Shallow test-pits reveal a sediment with characteristics consistent with sediment Type II, i.e., a diamicton deposited by subglacial melt-out. The crags, especially the higher ones, are commonly composed of amphibolite facies or quartzofeldspathic gneiss.

Sugden and John (1976), Boulton (1982), Hillefors (1973) and others suggest that crag-and-tail genesis may be associated with that of glacial flutes and correspond to the development of cavities down-ice of a boulder or bedrock obstruction. A cavity develops where ice flows over a high point on an irregular bedrock surface. The shape and dimensions of the cavity, and thus the tail, are determined by a series of factors, including horizontal and vertical ice-velocity, height of the bedrock hump and its length parallel to flow, and subglacial hydrostatic pressure (Boulton, 1982; Eyles, 1983). Crag-and-tail structures occur where water-saturated diamicton is squeezed into a cavity that has a low confining pressure compared to surrounding areas (Sugden and John, 1976). It is likely that the formation of crag-and-tail hills in the Strange Lake area is a result of a combination of processes, including migration of material into a cavity or low pressure zone, erosion and subsequent deposition of material derived from the crags, either by subglacial melt-out from the glacier sole, or lodgement of sediment where the sole comes into contact with the substratum. This diamicton, deposited in the lee of an obstruction has been termed 'lee-side till' (Hillefors, 1973). Sand and silt lenses observed within the diamicton, and near the surface (upper 1 m), imply that the glacier sole was not always in direct contact with the tail-forming material, because these structures would unlikely survive active ice modification.

On the up-ice side of bedrock crags, till 'ramps' are common. They are more steeply sloped than till tails, and are formed as debris-rich basal ice either stagnates or is lodged on the proximal side of an obstruction; ice on the up-glacier side consequently shears over and around the new obstruction (Eyles, 1983). The debris-rich ice melts-out *in situ* although lodgement on the upper surface is likely as till-ice contact is maintained (Boulton, 1970, 1982). Therefore, it may be expected that this stoss-side material is more compacted than that in the lee of the crag (Hillefors, 1973).

In the Strange Lake area, the crag-and-tail hills have a distinct asymmetric profile, the south-facing side being steeper than the north. This asymmetry is likely the result of postglacial snow patch accumulation on south-facing slopes and the accelerated erosion of these slopes during the melt season.

Eskers

The dominant features within the outwash terrain are esker ridges. These are well-defined forms 10- to 30-m high and 50- to 200-m wide (Plate 7). Individual ridges are commonly dissected by meltwater channels, or by lakes, although the esker systems are continuous for more than 50 km (Ricketts and Hayes, 1985), terminating in major modern

Table 3. Diagnostic characteristics of basal tills

	Lodgement	Basal melt-out
Stratigraphic position	Lowest till unit	Overlies lodgement till or is interbedded with lodgement till
Thickness	Decimetre to several metres; laterally discontinuous	Decimetre to tens of metres; sheet to discontinuous sheet
Matrix Texture	Unsorted; contains size ranges from clay- to boulder-sized material, depending on the source material	Variable, but is relatively depleted in silt–clay compared to lodgement till derived from same debris-rich ice
Consolidation	Commonly overconsolidated	Commonly normally to slightly overconsolidated
Structure	Massive; some fissility may be present	Commonly massive; lenses or laminae of silt or sand may be present; silt or sand coating around clasts common
CLAST		
Surfaces	Commonly abraded, striated and faceted	May be abraded and striated if transported in basal zone of high debris concentration
Shape	Classically 'bullet-shaped'; sub-angular to sub-rounded shapes common depending on distance of transport	Subangular to subrounded, depending on distance of transport
Preferred orientations	Oriented parallel to flow and dip up-glacier; strong fabric	More variable, but commonly oriented parallel to flow with an up-glacier dip
Lithologic components	Commonly reflective of local rock types, less variability than other till fabrics	Reflects farther distance of transport; far transported rock types more abundant than in lodgement till derived from the same debris-rich ice

Sources: Boulton (1976), Dreimanis (1976, 1982), Haldorsen (1983), Ashley *et al.* (1985), Drewry (1986).

Plate 4. *Till section in the Iron Ore Company of Canada trench at the Strange Lake deposit.*

drainage systems. Most major eskers occur along the southern margin of outwash channels, presumably reflecting the regional slope.

PERIGLACIAL FEATURES

Periglacial features are the result of postglacial modification of glacigenic deposits by freeze-thaw action. Three major types of periglacial features are observed, although not as mappable units. All features are active and reflect the fact that the Strange Lake area lies within the zone of discontinuous permafrost.

Mudboils

Mudboils are diapiric structures caused by the injection of fine grained material into near-surface horizons through a process of hydrostatic pressure buildup during the freezing season (French, 1976; Shilts, 1978) and subsequent upward release of pressure. They are common features in the Strange Lake area, on partly to well drained till surfaces. On the surface, mudboils are circular in shape where the angle of slope is less than 2°, devoid of vegetation and commonly have

Plate 5. *Glaciofluvial outwash sediments within a paleochannel along the southern shore of Strange Lake. Note the prominent esker ridge.*

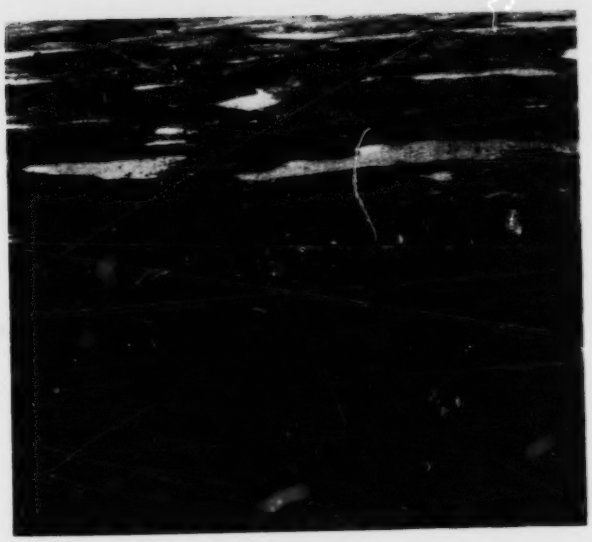


Plate 6. *Typical boulder-covered hummocks of diamicton within the outwash channel. The origin of these hummocks is unclear but may be frozen (?) blocks of diamicton released in the outwash system.*

a capping of clasts resulting from a process of upfreezing and the winnowing of fines (Plate 8). They range from centimetres to several metres in diameter, and may occur singularly or in groups seperated by organic mounds. Mudboils destroy the structure of existing soils but relict soil is commonly observed along the margins of mudboils as it is being reincorporated into the subsurface. On slopes greater than 2°, mudboils take on an elongate form (Plate 9).

Polygons

Well developed hexagonal-shaped polygons were observed in till at several isolated localities in the Strange Lake area (Plate 10). The origin of this patterned ground phenomena is not clear, although it is likely that cracking is the result of either thermal contraction, seasonal frost, or dessication, the latter process being independent of the need for permafrost. Washburn (1973) suggests that dessication through wind action is the most likely cause of the small, non-sorted polygons that characterize many upland tundra sites.

Solifluction Terraces

The downslope movement of sediment through a combination of gelifluction and frost creep is a common feature of a periglacial landscape. Solifluction terraces form a stepped, tread-like slope that ranges from 3 to 5° up to 15 to 20°. The relief of these features is less than 1 m in the Strange Lake area (Plate 11). The level part of the terrace is commonly devoid of vegetation, suggesting solifluction is still active.

MASS MOVEMENT

Small debris flows and flow-scars are also common in the Strange Lake area. Flows such as these commonly occur when the surficial sediment is exceptionally wet, and the water table rises causing an increase in pore-water pressure and consequent decrease in shear strength (Clayton, 1972). The usual trigger for movement is heavy rainfall onto an already saturated regolith. However, in the Strange Lake area, another unexpected possibility exists. The George River caribou herd, consisting of about 660,000 animals, ranges across the Strange Lake area (Jackson, 1986). In the summer, caribou are often observed around residual snow patches. During the course of field work, one of these groups of animals (about 250 caribou) was disturbed. The group moved across a snow bank overlying a steep-sloped (25 to 30°) surface saturated by rainfall and snow melt. Following the immediate departure of the caribou a mud-flow was observed to occur (Plate 12). The mud-flow ceased after about 20 minutes, leaving a 7-

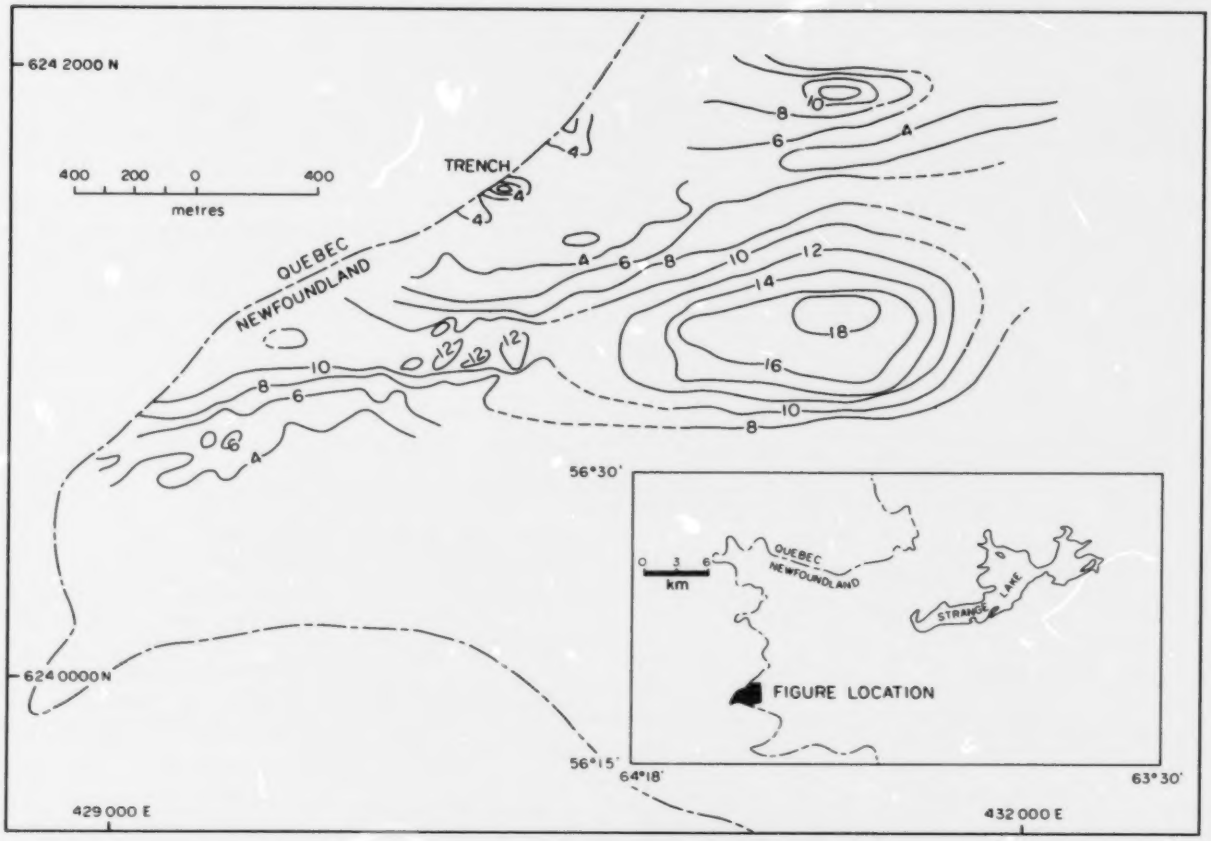


Figure 8. *Overburden thickness in the vicinity of the Strange Lake deposit.*

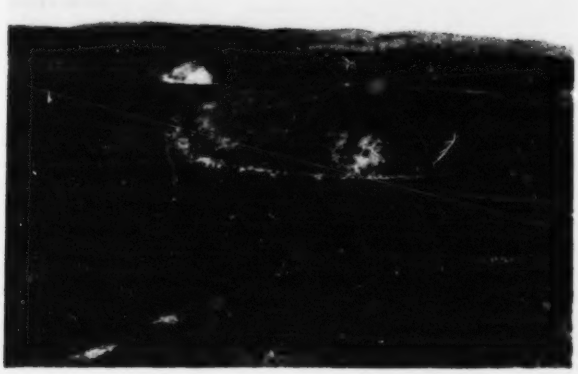


Plate 7. *Prominent esker ridge (about 25-m high) in paleochannel at the eastern margin of Strange Lake.*

Plate 8. *Circular mudboil with turf ridge margins. These are common features within areas of till in the Strange Lake area.*

Plate 9. *Elongate mudboil. These form on slopes in excess of 2 degrees.*

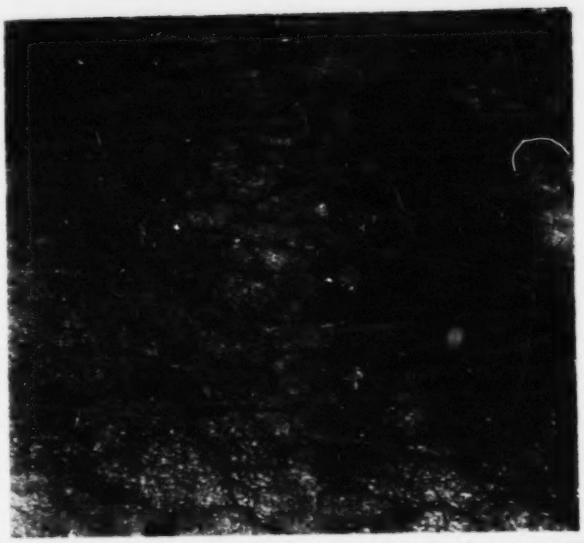


Plate 10. *Well-developed hexagonal shaped polygons in till at Strange Lake. These are likely the result of wind dessication.*

to 8-m wide and 0.75- to 1.0-m deep basin-shaped source area and a long (> 20 m) flow track.

Debris-movement scars are small-scale features (10- to 15-m wide and 10- to 30-m long), which are common occurrences along steep debris-covered slopes in the Strange Lake area. Whether the observed mud-flow (Plate 12), as the result of caribou, is an isolated case is presently unknown. However, tracks from caribou herds that break the vegetation and coalesce to form runnels are common on the tundra surface. Therefore, it is considered likely that caribou are a significant geomorphic agent in tundra areas.

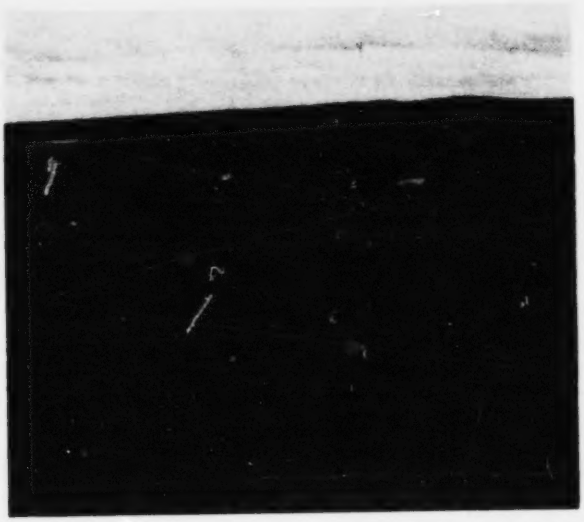


Plate 11. *Solifluction terrace at Strange Lake. Shovel for scale.*

GLACIAL DISPERSAL

INTRODUCTION

Within the last million years, the development of the Canadian landscape has been dominated by glaciers. Ninety-eight percent of the Canadian landmass has been affected by any or all of the numerous phases of glacial activity that have been identified, mainly from the offshore record. The legacy of this period remains in the form of eroded and moulded bedrock, and its debris dispersed down-ice as glacial deposits and other ice-related features and structures.

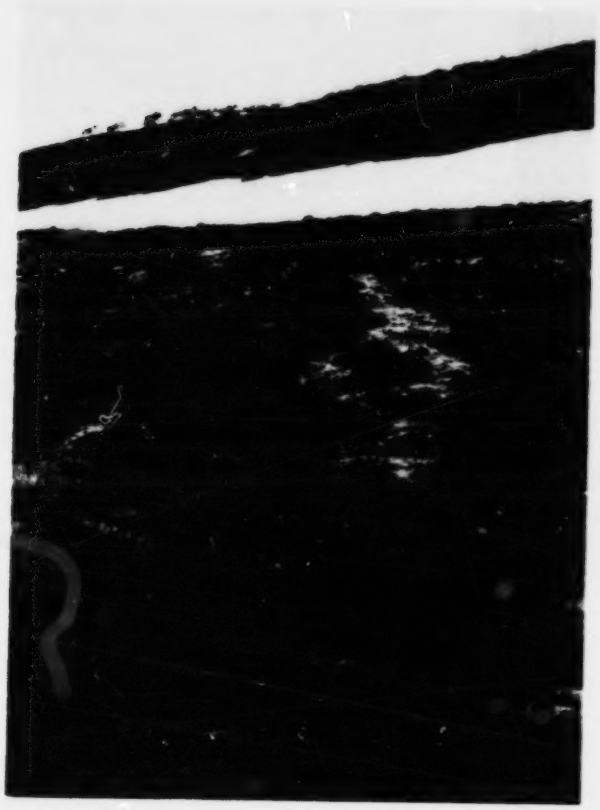


Plate 12. *A mudflow observed within saturated till downslope of a snow patch. The trigger for this mudflow was a herd of caribou moving across the snow patch (seen on the horizon). Caribou are probably a significant geomorphic agent within areas of sensitive vegetation cover.*

Historically, mineral exploration has focused on areas with abundant exposed bedrock. However, it is becoming increasingly more difficult to find mineralization that is not covered by glacial deposits, usually till, of thicknesses ranging from a veneer to tens of metres. Therefore, the prospective explorationist is often faced with the challenge of locating the source area from geochemical anomalies or mineralized boulders; a task that requires knowledge of glacial sediments and their mode of erosion, transportation and subsequent deposition.

TILL: AN AID OR A HINDERANCE TO MINERAL EXPLORATION ?

Dispersal processes are more clearly defined for till than for outwash or glaciofluvial sediments. Outwash and glaciofluvial sediment dispersal may be an order of magnitude larger than till and have flow patterns, which result from fluvial rather than glacial processes. As a consequence, mineralized boulders within outwash deposits are commonly widely removed from their source and do not form part of an easily identified dispersal train. The distribution of glaciofluvial deposits does not readily lend itself to drift exploration procedures, because the distribution of outwash is commonly restricted to paleochannels and is not evenly distributed across the surface.

Glacial diamicton (till), on the other hand, is common in the glaciated parts of Canada and is the sediment most often encountered in exploration programs. Diamicton is a term, used to describe poorly sorted sediment having a range of grain sizes from clay to gravel and for which no genetic environment is implied. Till is a material uniquely produced by glaciers, and may be defined as, 'a sediment that has been transported and is subsequently deposited by or from glacier ice with little or no sorting by water' (Dreimanis, 1982). Till consists of ground-up weathered and unweathered bedrock and pre-existing glacigenic sediments that have been eroded and deposited by glacier ice.

Diamicton deposited in a glacial environment may be classified into three basic types: 1) those related to frictional processes (lodgement tills), 2) those related to melting processes (melt-out tills), and 3) diamictons that are the result of mass movement. Lodgement is the deposition of till from the sliding base of a moving glacier by pressure melting and/or other mechanical processes (Dreimanis, 1982). In other words, material eroded from the bedrock by either crushing, abrasion or plucking by ice, and transported within the basal layer of the glacier, becomes 'lodged' against previously deposited material or due to friction with the substratum; lodgement is a gradual but active process. Clasts are commonly abraded on their upper surfaces following deposition (Kruger, 1979). If the rate of deposition is slow, then clasts take on a bullet-shaped profile as the stoss-sides are abraded and the lee-sides plucked (Boulton, 1978). With rapid rates of deposition, clasts are quickly buried and little erosional modification of the clasts occurs. During deposition, clasts often collide with one another producing an imbricate pattern with the long axis of clasts dipping up-glacier (Amark, 1980).

Melt-out tills are deposited by 'the slow release of debris from glacier ice that is not sliding or deforming internally' (Dreimanis, 1982). Melt-out tills may be deposited either sub- or supraglacially from either wholly stagnant glacier ice or a stagnant debris-rich ice body beneath active ice. The melt-out process is thus a passive one; the major distinguishing characteristic between the melt-out and lodgement processes. The final deposit, therefore, inherits some characteristics from pre-depositional transport in glacier ice, whereas lodgement tills are commonly modified after deposition. Melt-out tills are also coarser than lodgement tills derived from the same debris-rich ice (Haldorsen, 1981).

If a sediment melts out on the glacier surface, it may be deposited *in situ* if there is little free water and sublimation accounts for most of the ice loss (Drewry, 1986). The resultant supraglacial melt-out till is commonly less comminuted, has more angular clasts that lack striations, and a low density and frequent voids compared to a basally-deposited till (Boulton and Eyles, 1979). If water liberated through melting

is not well drained, supraglacial sediment may become saturated and flow downhill under its own weight (Drewry, 1986). Such a sediment does not meet the criteria for till discussed earlier, although resedimentation of this kind has commonly been termed 'flow till' (Boulton, 1968). The flow processes destroy the original character of the till, and although this type of sediment may be readily described from modern glacial environments, where it commonly forms a large proportion of glacially related sediments (e.g., Lawson 1981), its similarity to tills makes identification difficult. However, these processes occur close to ice and, from a practical viewpoint, may be regarded as glacial sediments.

Till genesis is complex, and determining an environment of deposition for a given sediment may be difficult. No individual characteristics are diagnostic of a particular genesis but combinations of criteria may be used to seperate till types derived from similar sources. These are summarized in Table 3.

Understanding of till genesis is important to an exploration program. A contrast in transport distances of clasts and matrix may be expected between lodgement tills that have a tendency to be transported short distances compared to subglacial melt-out tills, which may be of distal provenance (Figure 9) (Geddes, 1982; Hyvarinen *et al.*, 1973).

The mode of erosion, transportation and deposition of till also results in mineralogical differences. Haldorsen (1983) has shown that contrasts in comminution processes, specifically between abrasion and crushing, causes mineralogical fractionation. This is partly related to the concept of 'terminal grades' (Dreimanis and Vagners, 1971). Their research determined, experimentally, the size fractions in which various rock-forming minerals are most abundant. It is primarily a function of mineral strength, with contrasts between harder, less cleavable minerals such as quartz, K-feldspar, barite, which form coarse fractions, and softer, cleavable minerals such as micas, hematite and graphite, which form silt/clay sized material. Haldorsen (1981) notes that the grain-size following disintegration retains the grain-size of the original, unweathered bedrock. The second factor in mineralogical fractionation is related to till deposition. Lodgement tills generally have a larger silt−clay matrix than melt-out tills because of continued abrasion following lodgement, and because winnowing by interstitial water movement can remove the fine component from melt-out tills. Melt-out tills are consequently depleted in sheet silica-rich and feldspar components, and thus chemically in alumina, sodium and potassium (Haldorsen, 1983), because these minerals are concentrated in the silt−clay fraction. Lodgement tills may, therefore, be expected to have elevated geochemical values for those elements concentrated in the finer fractions relative to melt-out tills.

Therefore, an understanding of till genesis is important in studying glacial dispersion, as it probably causes mineralogical and geochemical variability of the resulting sediment. The key factor is consistency: sample the same material and identify the facies being sampled (i.e., sample melt-out or lodgement tills, but not both), or sample both and group the data separately.

FACTORS OF GLACIAL DISPERSAL

Glacial sediment is eroded bedrock that is transported along specific flow-paths and deposited through the action of glacier ice. If the bedrock source is lithologically or geochemically distinctive, the path of glacier movement may be recorded as a dispersal train. Mineralized boulders or geochemical anomalies may, therefore, form part of a dispersal train, which may be traced back to its source in bedrock, the essence of boulder tracing or drift prospecting.

However, there are two factors that determine the textural and geochemical composition of glacial sediment at a site, apart from sediment genesis. These are the source of the sediment and the characteristics of the dispersal area.

Source of Sediment

The amount of bedrock eroded is dependent on its nature (hard versus soft, permeable versus impermeable), and the bedrock topography and structure (Shilts, 1982; Minell, 1978). If the bedrock is soft (e.g. limestones, shales), well-jointed or permeable, a large amount of material may be available for transport. Alternatively, hard, massive, impermeable rocks (e.g., granites, rhyolites) will provide relatively little material. Similarly, the texture of the till is also determined in part by the nature of the source bedrock (this relates to the previously discussed concept of 'terminal grades'; Dreimanis and Vagners, 1971).

The bedrock topography determines the ease of erosion by causing pressure differences at the base of the ice. Subglacial pressure is higher on the up-ice side of bedrock obstructions allowing enhanced potential for erosion and is lower on the down-ice side. Rapid topographic changes cause pressure variations around roches moutonées inducing shear stresses that may enhance erosion.

The Dispersal Area

The topography of the dispersal area will affect the shape and continuity of the dispersal train (Shilts, 1975, 1982). If the land surface is subdued, the shape of the train is controlled by the distance of glacial transport and the rate of deposition of the clasts or geochemical indicator components. In irregular topographic areas, ridges or valleys may block or divert debris-rich basal ice thereby destroying, displacing or truncating dispersal trains.

NATURE OF DISPERSAL TRAINS

The processes of glacial dispersal have been discussed in some detail. The form of a dispersal train depends on the factors outlined above, especially the topography of the dispersal area, as well as the frequency of glacial events that have affected an area. A narrow, finger- or ribbon-type train

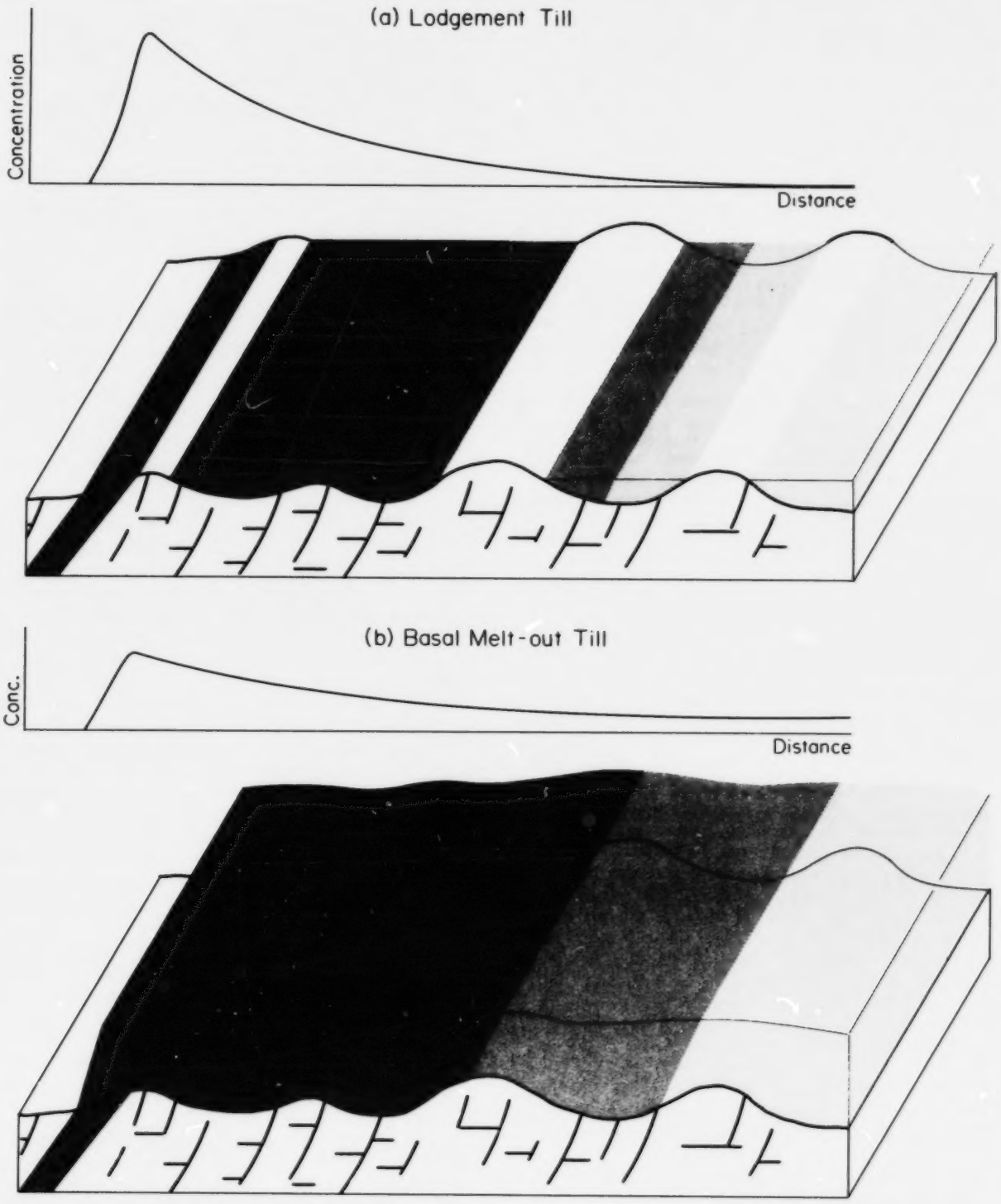


Figure 9. *A model illustrating the contrast in transport distances between lodgement and melt-out tills. Lodgement till commonly have a greater concentration of indicator components and shorter transport distances compared to melt-out tills.*

may be expected if only one glacial event occurred, assuming no topographic effects (Hyvarinen *et al.*, 1973; Klassen and Shilts, 1977; DiLabio, 1979, 1981). This type of train has been reported from a wide range of localities (e.g., Dreimanis, 1956; Holmes, 1966; Shilts, 1972, 1975; DiLabio, 1979; Miller, 1984). If glacial flow had been in more than one direction, resulting either from several glacial events or changes in the dynamics of an ice mass, then a fan-shaped train would result (Flint, 1971; Hyvarinen *et al.*, 1973).

Dispersal trains may be either positive or negative geochemical or lithological anomalies, i.e., much higher or much lower than the regional background values, and range from tens of metres to tens of kilometres in length. However, certain general characteristics prevail. At the up-ice end of a dispersal train the frequency of indicator components whether geochemical or lithological, in a given grain size, increases rapidly to a peak and subsequently declines gradually. These two basic components of the dispersal train are termed the 'head' and 'tail' (Figure 10; Shilts, 1982). Consequently, it can be concluded that most material in a train is transported a short distance from its source. At a greater distance down-ice, the indicator components become diluted by increasing amounts of more local debris.

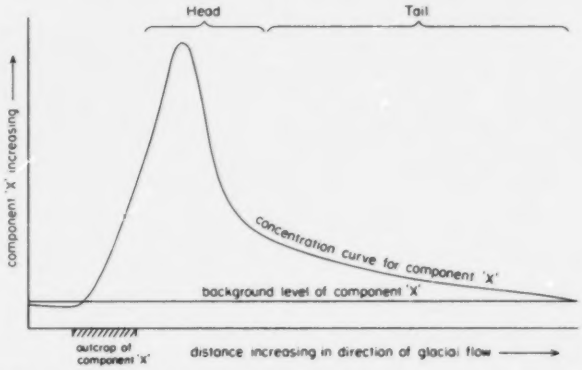


Figure 10. *An idealized glacial dispersal curve (after Shilts, 1982).*

Figure 10 shows that peak geochemical values are not reached until a certain distance down-ice of the source, and similarly, mineralized boulders are rarely observed directly over their source. What factors lead to this situation? Clearly, dispersal of till is not simply a two-dimensional distribution and must include a third dimension, that of upward-trending dispersal through a till sheet (Hyvarinen *et al.*, 1973; DiLabio *et al.*, 1982; Drake, 1983; Miller, 1984).

The distance between the source area and the peak surface abundance for any component, the K-value of Lee (1965), is dependent primarily on till sheet thickness (Figure 11) (Grip, 1953; Dreimanis, 1956; Drake, 1983; Miller, 1984).

Of relevance to exploration programs, are the processes by which sediment reaches the top of a till sheet. Glacial erosion occurs sporadically or continuously, depending on a variety of factors including bedrock topography, ice thickness, ice velocity and basal thermal conditions. Material is entrained at the base of the ice and transported basally or englacially. To develop a dispersal train, Drake (1983) suggested the concept of 'sequential stacking or smearing of basal tills resulting from alternating cycles of erosion and deposition'. In this model, each successive till sheet becomes the source for subsequent erosion and deposition. This results in a graded till mass that has been increasingly remobilized and re-entrained in its upper portions, producing a step-like sequence. This model assumes all bedrock erosion occurs at one time, because the deposition of the first till sheet will cover the bedrock source. This could result in a small dispersal train if the bedrock source is resistant to erosion, and this is inconsistent with the many extensive trains described above. Miller (1984) suggested entrainment of sediment along smear or thrust planes, and subsequent deposition by passive melt-out. This results in little diffusion or mixing and is consistent with the coherent, high contrast, ribbon-type trains observed. The difference between these lodgement or melt-out processes may explain the differences in the extent and form of dispersal trains.

No matter how the dispersal train is derived, surface geochemical anomalies and mineralized boulders are located down-ice of their source. The distance down-ice is mainly a function of till thickness. Supporting data comes from a wide range of drift dispersal studies and are summarized in Table 4.

Table 4 shows that dispersal trains climb down-ice at an angle that ranges from 0°30' to 3°50' with a mean value of 1°50'. In terms of exploration this suggests that the source of mineralized bedrock would be about 21 m up-ice (range between 15 and 115 m) of the peak geochemical values or first down-ice occurrence of mineralized clasts for every 1 m of till encountered. Bayrock (1985) suggests 16 m for every 1 m of overburden. It is unlikely that this empirical relationship will hold up in all cases because the type of dispersal will vary with the depositional environment of the till. As discussed earlier, a lodgement till contains a higher proportion of local material than a basal melt-out till. Therefore, it is likely that for a given till thickness, the K-value for a lodgement till should be less than that for a basal melt-out till.

Thus, an important third-dimension exists to glacial dispersal. This can be recognized in exploration programs by sampling both vertically and horizontally. However, from an exploration standpoint, the benefits of profile sampling (by drilling or trenching) on a regional scale must be weighed against the higher cost involved. Near surface sampling is cheaper and detection of the dispersal train may require a less dense sample spacing, although values may be lower in a surface anomaly compared to subsurface values for the reasons outlined previously. However, it is suggested that overburden drilling or trenching is an important follow-up tool once a surface anomaly has been delineated.

Naturally, most glacial environments are not so simple as to have low relief bedrock topography, unidirectional flow, one till facies and a single, discrete orebody. In many instances, a stratigraphic sequence is found, e.g., a basal melt-

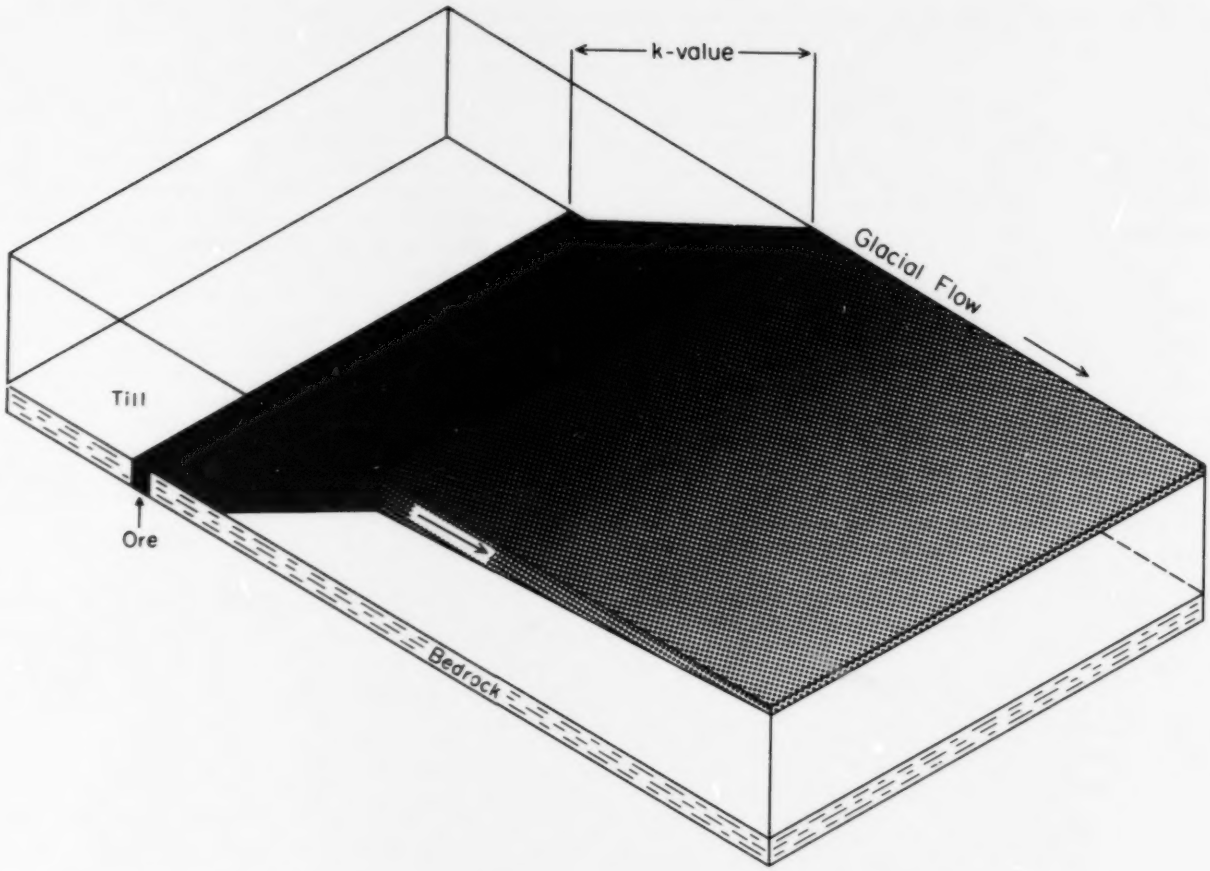


Figure 11. *A three-dimensional view of glacial dispersal through a till sheet (modified from Miller, 1984).*

out till overlying a lodgement till. The characteristics of each of these depositional environments has been described (Table 3), and their influence on dispersal patterns is summarized in Table 5. Schematically, these characteristics are presented in Figure 12.

DISPERSAL FROM THE STRANGE LAKE DEPOSIT

The Strange Lake deposit forms a topographic high that straddles the Labrador–Québec border, and satisfies one condition (see previous section) for producing a well developed dispersal train. Down-ice of the deposit, is a peneplain surface, which has few topographic obstructions to dispersal train development. Ice-flow directions are generally unidirectional. The area is, therefore, ideal for studying the effects of glacial dispersal in the surficial environment.

SAMPLING METHODS

Sampling was carried out during the summers of 1983 and 1984. Quaternary deposits, predominantly till, were sampled from over 550 sites and 1081 samples were collected. This provides a nominal sample density of 1 site per 1.97 km², although in the vicinity of the Strange Lake complex, the sample density increased to about 1 site per 0.5 km² or less. Soil profile sampling of B, BC and C horizons was completed, where possible, to determine the geochemical profile, and similarly, vertical sampling was also undertaken within the C horizon to determine grain-size distribution changes as well as geochemical variations. Mudboils were also sampled. In this area, mudboils are found almost exclusively on till, and are therefore an aid in sample control. The till that is mobilized in the diapiric part of the mudboil is usually fresh, having been injected from depths of 1 to 1.5 m.

In addition to geochemical sampling, clasts (8- to 32-mm diameter) from within the till and boulders from the surface were collected and identified. The objective was to determine both glacial transport directions and distances, within the study area.

Table 4. Relationship of K-values to till thickness

Author		Place	Mineralization	K-Values (m)	Till Thickness (m)	Angle of Plane
1.	Grip (1953)	Harmsarvet, Sweden	Ag	700	6	0°30'
2.	Nilsson (1973)	Mjovaltnet, Sweden	Ni	150	10	3°50'
3.	Minell (1978)	Rebraure, Sweden	U	40-50	3-5	3°20'
4.	Minell (1978)	Skarjaviken, Sweden	Mo	200	4-5	1°50'
5.	Minell (1978)	Kikkejaure, Sweden	U	200-300	2-6	0°34'-1°10'
6.	Minell (1978)	Labbas, Sweden	U	60	2-5	1°50'-4°46'
7.	Minell (1978)	Harrejok, Sweden	U	250-300	2-6	0°23'-1°43'
8.	Minell (1978)	Tjarrovare, Sweden	Cr	350	2-8	0°20'-1°20'
9.	Miller (1984)	Bathurst Norsemines, Canada	Pb	450-500	2-8	0°14'-0°55'
10.	Miller (1984)	Lough Derg, Ireland	Pb	800	8	0°34'

ANALYTICAL METHODS

Particle-size Analysis

Matrix samples (< 2 mm/-1Ø) were split to provide a 100- to 150-g sample and wet sieved through a 63 μm (4Ø) sieve. The retained fraction was oven-dried and sieved through a nest of 6 stainless-steel sieves (4Ø to -1Ø) following the procedure outlined by Bowles (1978). The finer than 63 μm fraction was analyzed for particle-size distribution using a Coulter Counter, Model TAII-L. Using 2 separate apertures, grain size was measured between 0.002 mm (9Ø) and 63 μm (4Ø).

Geochemical Analyses

There has been considerable discussion on the optimum size fraction for geochemical analysis of tills (Shilts, 1972, 1975, 1976, 1982; Klassen and Shilts, 1977; DiLabio *et al.*, 1982). Shilts (1982) demonstrated that for a small nickel showing in the Keewatin area, Northwest Territories, the clay fraction (< 2 μm) best delineated dispersal patterns compared to the patterns produced from the silt–clay (< 63 μm) fraction. This is because the clay fraction contains phyllosilicates that may either contain or scavenge metals released by weathering of labile components, whereas the silt fraction is generally metal-poor and is dominated by quartz and feldspar. Silt thus dilutes metal values in a silt–clay analyzed fraction. However, although analysis of the clay fraction produces a higher anomaly/background contrast, dispersal patterns are commonly distinguishable for each fraction analyzed. The increased sample preparation involved in centrifuging samples to produce a clay (< 2 μm) fraction would increase analytical costs. In this study, the grain size and mineralogical composition of the regional bedrock (predominantly gneisses) make this process unnecessary. The low concentration of clay in the tills in the area would have made analysis of only the clay fraction difficult.

The silt–clay fraction was recovered for geochemical analyses from the original sample by sieving. Ag, Be, Cd, Co, Cu, Fe, Li, Mn, Mo, Ni, Pb and Zn were analyzed by atomic absorption spectrophotometry after a nitric acid

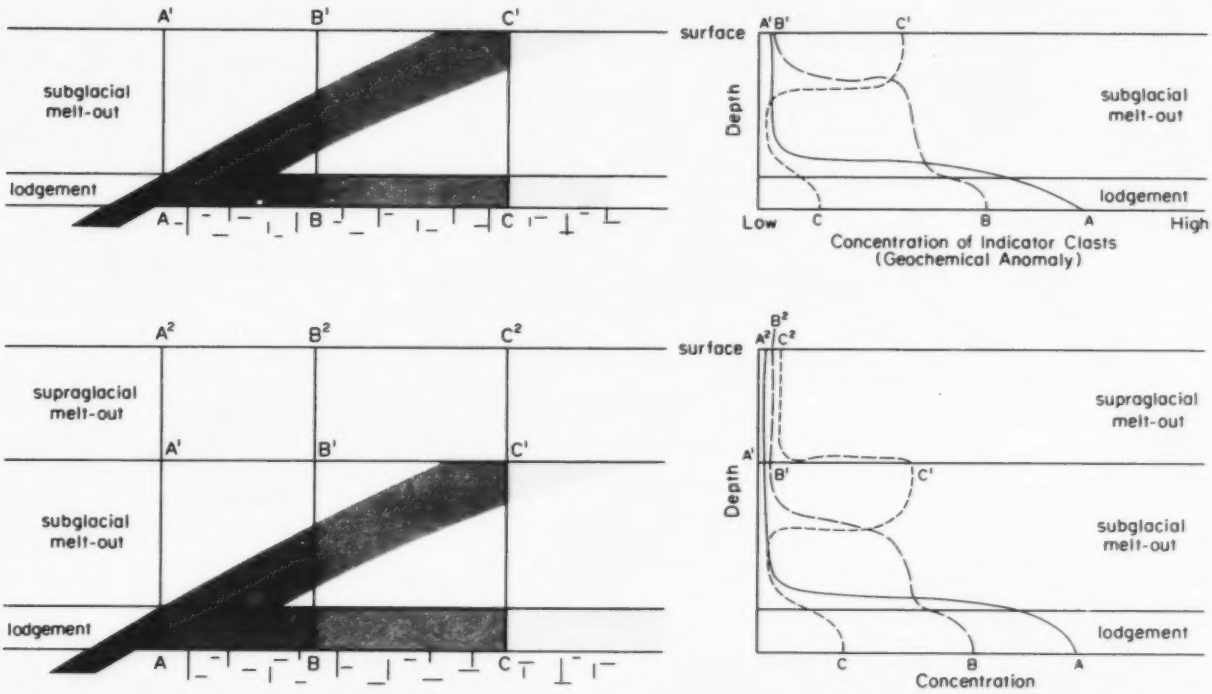


Figure 12. *A model illustrating the effect of stratigraphy on glacial dispersal patterns. A single deposit type (e.g., lodgement till, melt-out till) will have well developed vertical changes in indicator component concentrations, but when different till types are superimposed on each other, complex vertical variations occur.*

Table 5: Lodgement till characteristics and their effect on glacial dispersal patterns compared to basal melt-out till

Lodgement till characteristic compared to melt-out till		Effects on dispersal
1)	Lodgement till deposited closer to outcrop	Lower K-values
2)	Lodgement till commonly thinner	Shorter and narrower dispersal trains
3)	Shorter overall transport for lodgement till	Higher anomalous geochemical values

digestion and hydrochloric acid leach: Ba, Ce, Cr, Ga, La, Nb, Rb, Sr, Th, V and Zr were analyzed by X-ray fluorescence; F by ion specific electrode; and U by delayed neutron activation. In each block of 20 samples, a duplicate sample and a reference standard of known composition were included to determine accuracy and precision.

RESULTS

Dispersal of Clasts

Mineralized clasts are dispersed at least 40 km down-ice from the Strange Lake deposit (Figure 13). Even at this distance, 1 to 4 percent of clasts are derived from the complex. The general down-ice pattern is similar to the generalized dispersal patterns of Shilts (1982), i.e., a rapid peak followed by a gradual decline farther away from the source. Close to the deposit, high concentrations are recorded with a maximum of 52.1 percent mineralized clasts. Generally, within 1 km of the margin of the deposit, mineralized clasts within the till are below 10 percent, and gradually decline in proportion down-ice.

Several areas of anomalously high mineralized clast concentrations occur outside the area defined by the Strange Lake deposit (Figure 13). Although several are unexplainable, the seven easternmost highs, and the single south-westernmost one, are related to either discrete topographic highs or to crag-and-tail hills. For example, in the area surrounding a crag-and-tail hill 16 km down-ice of the Strange Lake deposit, clasts related to the deposit account for between 1 percent and 5.1 percent of the total clast content. The crag-and-tail itself yields values considerably higher (Figure 14). The ramp has 6.9

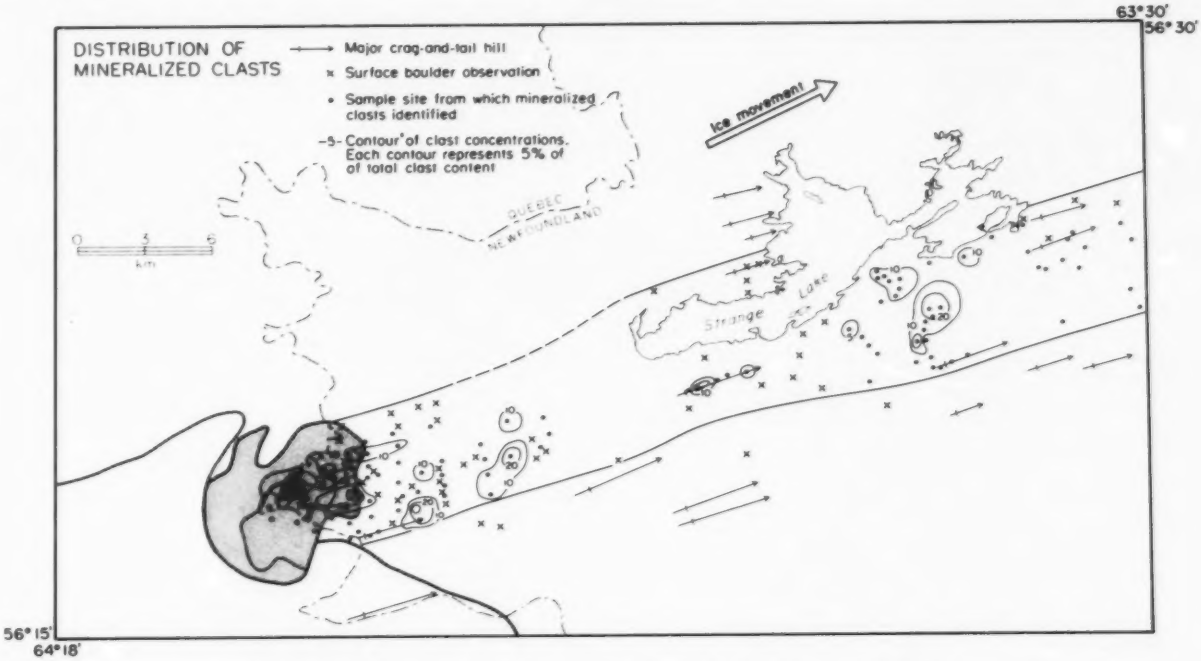


Figure 13. *Distribution of mineralized clasts in the Strange Lake area.*

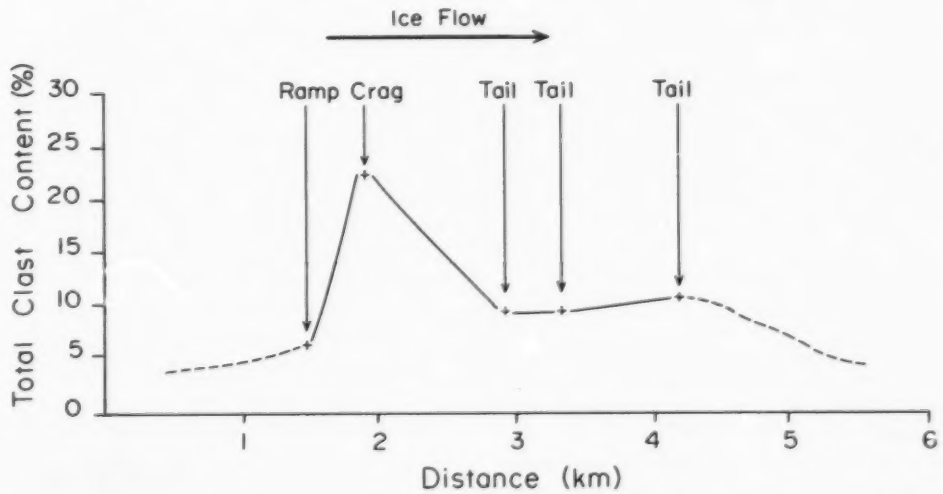


Figure 14. *A graph illustrating the mineralized clast distribution over a crag-and-tail hill.*

percent mineralized clasts, the crag 22.6 percent and the tail 9.2 percent, 9.4 percent and 10.7 percent at increasing distances from the crag. Similarly, an area of small, yet well defined crag-and-tail hills, 24 km down-ice of the Strange Lake deposit, yields values ranging from 10.9 percent to 26.8 percent mineralized clasts with a majority greater than 15 percent. This is in contrast to the surrounding area, which records values of 1.5 percent and 6.4 percent. It is therefore apparent that the presence of topographic highs has influenced deposition of glacially entrained material.

In section, distinct trends in mineralized clast abundance are also observed. Within the Iron Ore Company of Canada trench, the increase in mineralized clast content within the lowermost till unit has already been discussed. Of perhaps greater significance are the lithological variations within a 5.5-m section exposed along the sides of a meltwater channel about 3 km down-ice of the trench. Within a 4-m-thick unit of diamicton interpreted as basal melt-out till, less than 2 percent of the clasts are mineralized. Underlying this diamicton is a pink-coloured horizon that contains up to 77 percent of angular, mineralized clasts, which are primarily

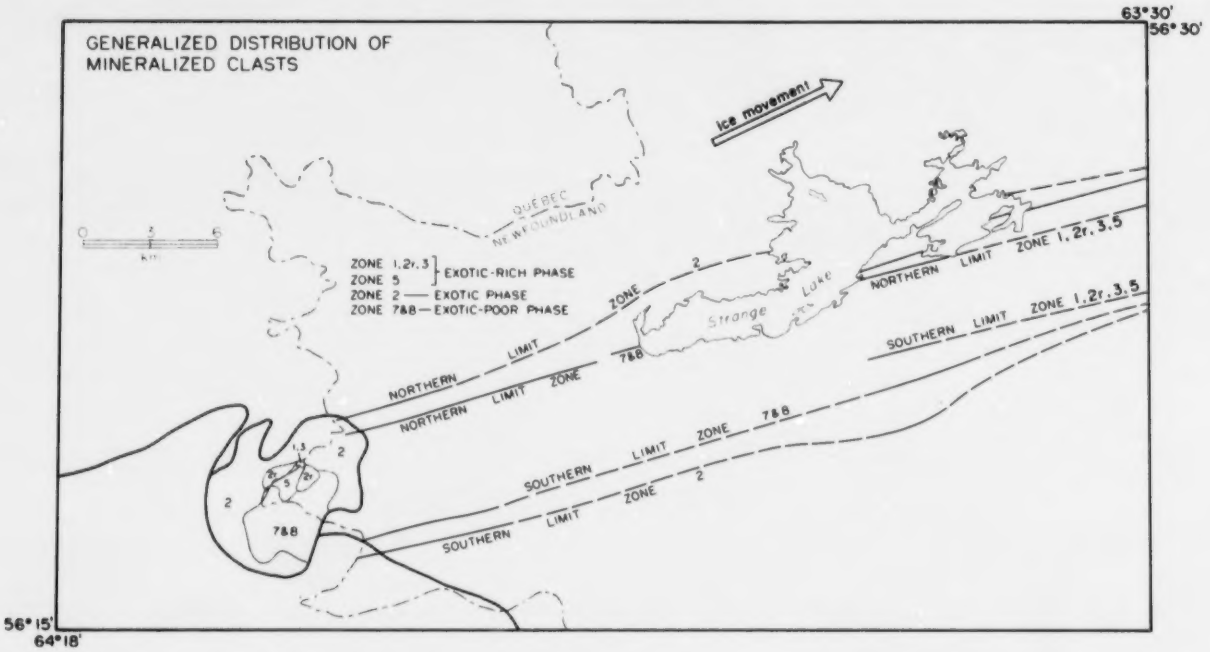


Figure 15. *Generalized distribution of mineralized clasts from different units of the Strange Lake peralkaline granite.*

a medium grained, exotic, inclusion bearing granite. The pink colour is caused by red riebeckite crystals. These characteristics are consistent with an outcrop discovered within the meltwater system during follow-up work, and to frost-heaved bedrock underlying the diamicton. The abundance of clasts, their angularity and their proximity to a bedrock source suggests a short transport distance (< 50 m?).

Apart from the general down-ice decline in values and its length, the other striking feature of the train is its width. At 40 km from source, the width of the train is 6.2 km, compared to a 7.2-km width of the complex itself (Figure 15). The reason for this apparent decrease is unclear. One factor may be the topographic aspect of the northern part of the deposit. It's location on a north-facing slope and within a valley that was probably the site of subglacial meltwater activity, would have effectively 'removed' this part of the deposit from the dispersal train defined in till.

The peralkaline granite has been subdivided into a series of discrete, visually distinctive bedrock units (Figure 15). The distribution of material from these units, down-ice of the complex, shows that discrete flow patterns existed within the glacier transportation system. Exotic-poor clasts have a broad distribution pattern (Figure 16; Table 6) that largely mirrors the combined mineralized clast dispersal pattern, except in the north part of the train, near the complex. Exotic-poor outcrop covers the southern part of the deposit and, in general, there are few clasts of this type noted north of expected flow lines. The concentration of exotic-poor clasts that does occur is down-ice of a small inlier of exotic-poor bedrock within the exotic group. Anomalously high concentrations of exotic-poor clasts 25 to 30 km down-ice of the complex are also found.

The dispersal pattern of exotic clasts (Figure 17) also demonstrates down-ice consistency and is similar to the exotic-poor lithology distribution (Figure 16). Although the exotic phase encompasses the largest area, dispersal from the northern part is not clearly defined because it occurs within outwash sediments.

The exotic-rich phase outcrops over a small area and therefore produced relatively little material (Figure 18). Clasts occur down-ice of the complex for up to 5 km but were not detected again until 25 to 30 km down-ice, where they occur in association with topographic highs. A number of boulders were observed south of the mapped outcrop and likely relate to dispersal from a series of small exotic-rich plutons within the complex.

Adamellites having a rapakivi granite texture outcrop to the west and south of the complex. They have distinctive weathering characteristics that enables easy field identification. The distribution of clasts of this rock type generally reflects the outcrop of its source, which is mainly south of Strange Lake. The highest clast concentrations are in the west and decrease down-ice with accompanying anomalies corresponding to topographic highs. The broad area of outcrop, the consequent large volumes of material potentially removed and the lack of detailed bedrock mapping means that only general dispersal trends are defined.

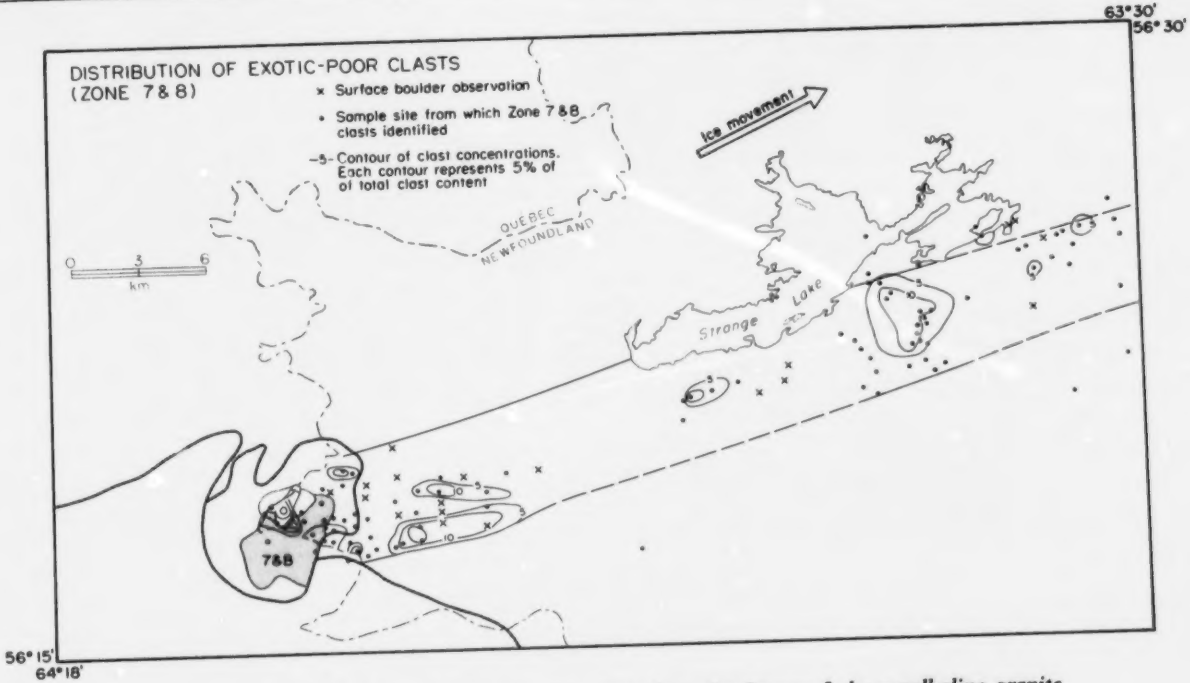


Figure 16. *Glacial dispersal of exotic-poor clasts from the Strange Lake peralkaline granite.*

Table 6: Characteristics of dispersal from subunits of the Strange Lake peralkaline granite

Bedrock outcrop		Dispersal train			
Zone[1]	Width[2]	Widest Point	Distance[2]	Narrowest Point	Distance[3]
7 & 8 (exotic-poor)	3.9 km	5.7 km	25.9 km	1.8 km	36.7 km
2 (exotic)	7.2 km	5.4 km	27.5 km	2.3 km	35.0 km
2R (exotic-rich)	1.3 km	4.0 km	32.0 km	Insufficient data	
3 (exotic-rich)	0.8 km	1.8 km	30.0 km	Insufficient data	
5 (exotic-rich)	1.0 km	1.4 km	28.0 km	Insufficient data	

1 After Miller (1986)
2 Bedrock width transverse to flow
3 Distance down-ice of closest outcrop

In all the cases documented above, there is evidence of considerable transport distances. Within the study area, maximum transport is at least 40 km, and it is expected that a clearly defined dispersal train extends for at least 55 km and probably farther. Airborne geophysical surveys support this observation, particularly airborne spectrometry (Geological Survey of Canada, 1986). Distribution maps derived from this survey (GSC, 1986) for uranium, total count and especially thorium, match the identified pattern of clast dispersal (Figure 19). The well defined geophysical pattern extends outside of the study area to the vicinity of Anaktalik Brook, beyond which the pattern becomes more diffuse. It is not apparent what the mineralized content of the surface sediment must be to affect airborne data, but it is likely that remnants of the train (i.e., less than 0.01 percent of the surface clasts) should be observable for many more kilometres, probably out to Nain Bay, 110 km down-ice of the complex. Transport of this magnitude is compatible with that documented in other parts of Labrador (Thompson and Klassen, 1986).

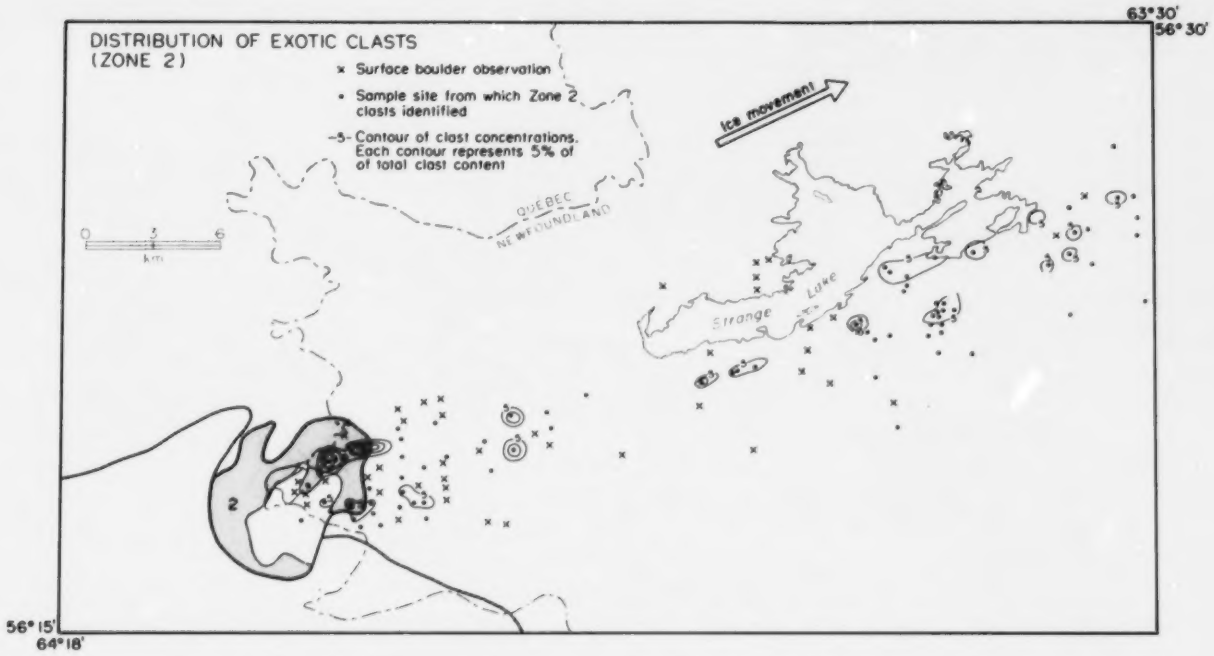


Figure 17. *Glacial dispersal of exotic clasts from the Strange Lake peralkaline granite.*

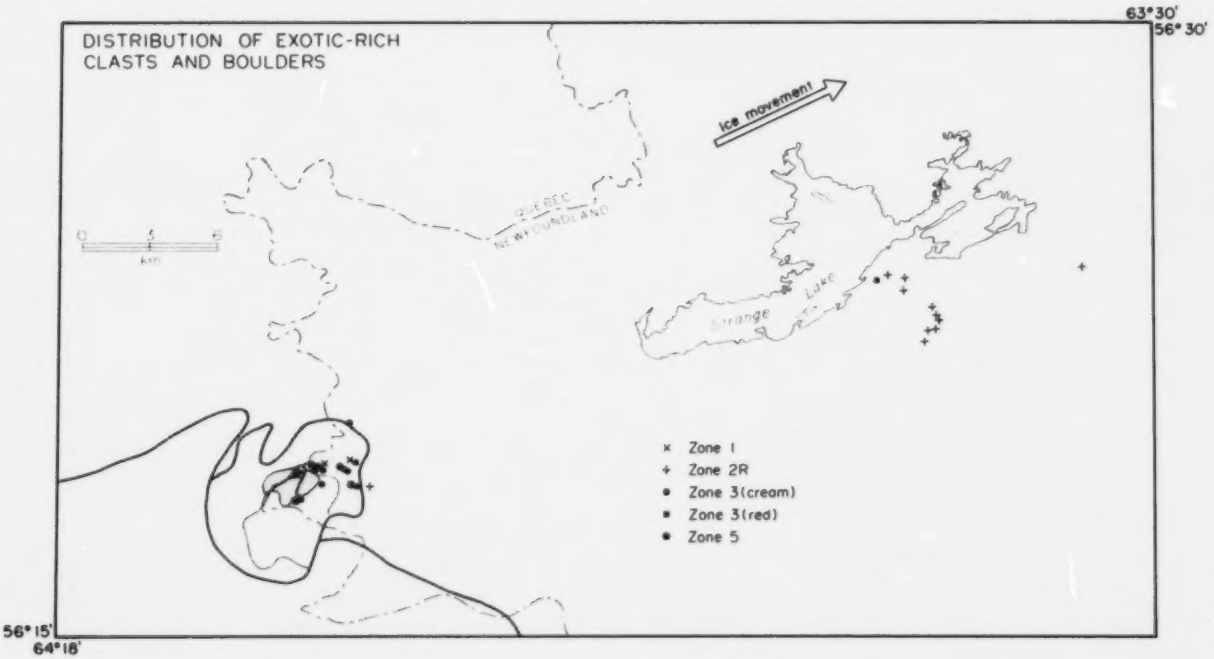


Figure 18. *Glacial dispersal of exotic-rich clasts and boulders from the Strange Lake peralkaline granite.*

Soil Horizon Geochemistry

It is apparent from an examination of the geochemical literature that no consensus of opinion exists as to whether A, B, BC or C soil horizons provide the highest anomalies relative to a regional background. Background is defined as the, 'normal range of concentrations for an element, or elements, in an area (excluding mineralized samples)' (Levinson, 1974). Hawkes and Webb (1962) record that for a mature soil profile, C horizons may show anomalies near

Figure 19. *Distribution of equivalent thorium concentrations from airborne gamma ray spectrometry data on the Nain plateau.*

to the subcrop of a deposit, whereas at a distance from the subcrop the B horizon has a relative enrichment. Levinson (1974) showed a generalized profile for podzolic soils that recorded a peak in base-metal values in the B horizon, whereas Klassen (1984) showed that C horizons have the highest values for clay-sized material when analyzing trace elements. Similarly, Hornbrook *et al.* (1975) concluded from a geochemical study in the Daniel's Harbour and New Bay Pond areas of Newfoundland that C horizons give results more reflective of underlying bedrock than B horizons.

Levinson (1974) concluded that for an exploration geochemistry program, all soil horizons in an area should be sampled and analyzed. Similarly, because there is a preferential concentration of some elements in certain horizons within any soil profile, the concept of anomalous values is dependent on knowing what these relative concentrations are, i.e., each individual soil horizon may be considered to have its own background value (Hawkes and Webb, 1962). As such, the determination of what is considered as background is fundamental to determining what values are anomalous. The highest value in a soil profile should not be necessarily equated with the most significant.

In the Strange Lake area, 305 B horizons, 228 BC horizons and 157 C horizons developed on till were sampled, thus providing the opportunity to determine the most anomalous horizon. Silver, Cd and Mo were either at or below detection limit in all cases and are not considered in any further discussion. From an examination of the geochemical dispersal maps (see Figures 24 and 25), it is evident that till over gneissic terrane outside the train is geochemically 'dead' relative to that derived from the peralkaline granite. Till on the gneissic terrane was therefore considered to define the background values for the Strange Lake area (Figure 20; Table 7).

Comparison of elemental background values shows a general increase in median values from the B to C horizons, except for iron. Zirconium for instance increases from a median of 222 ppm in the B horizon to 473 ppm in the C horizon. The application of a non-parametric, two-sample median test showed that the differences in the medians between soil horizons were statistically significant at the 95 percent confidence level, for all elements apart from Cr, Nb, Pb and V. Such a knowledge of differing background values can be applied to values from within the dispersal train (Figure 20; Table 8). A random distribution of sites were selected both adjacent to and down-ice of the Strange Lake deposit to remove the possibility of skewing data due to excessive concentration of sample sites near the deposit.

Of the 23 elements considered, Be, Co, Cr, F, Ga, Nb, Pb and V showed no statistically significant variation between the B, BC and C horizons at the 95 percent confidence level. Of the remainder, the B horizon had the highest value for Fe only. Traditionally, this has been the approach in the treatment of geochemical data, i.e., the concept that the highest value is equated with the most anomalous. However, when the background values are considered, the contrasts between B and C horizons are commonly reversed. For the 15 elements having a statistically significant between-horizon variation, the B horizon is more anomalous compared to its background for Ce, F, Rb, U and Zr. Zirconium for instance has B, BC and C horizon median values of 555, 631 and 851 ppm respectively, but the B horizon was 2.50 times its background compared to 2.33 times and 1.80 times for the BC and C horizons, respectively. Simply because a geochemical value is higher in one horizon compared to another within the same profile does not necessarily mean it is more significant.

Despite these constraints, a clearly defined dispersal pattern is evident using either B or C horizon data. However, it is important to realize that the highest sample value does not necessarily mean that it is the most anomalous, and the suggestion of Levinson (1974) that an orientation study, of all the soil horizons, should be undertaken before any particular horizon is selected is a sound approach.

Within the exploration industry, there is a tendency to sample the B horizon because it is easily recognizable and is the easiest to sample on a regional basis. In the Strange Lake area this is a reasonable approach, although for some elements (e.g., Zr) the BC or C horizon geochemical values are considerably higher than in the B horizon. Table 8 and Figure 20 show that most of the deposit-related elements are enriched in the BC or C horizon. A non-parametric Mann-Whitney test designed to test whether 2 groups are significantly different was applied to the B, BC and C horizons. It showed that at the 95 percent confidence level there was a significant difference between the B and BC horizons, and between the B and C horizons, for all elements except Ga, Pb and V. However, there was no significant difference between the BC and C horizons, except for Zr. The implication of this test is that for most elements, penetration to the C horizon is unnecessary to provide a representative sample for geochemical analysis. It is sufficient to penetrate beneath the B horizon.

The correct identification of the parent material on which the soil profile is developed is an important factor in geochemical sampling. In the Strange Lake area, the uniformity of glacigenic sediments makes recognition of the parent material from B horizon samples straightforward. However, in areas where different types of tills are evident or where poorly sorted outwash material and tills are in proximity, sampling of only the B horizon may result in erroneous conclusions concerning the parent material and lead to confusing or misleading patterns. Such errors occur because weathering tends to mask the physical properties of a parent material. Therefore, it is essential to penetrate beneath the B horizon to verify that the same sediment is being consistently sampled. If this approach is used, C, BC and B horizons should be sampled because elemental affinities for certain horizons cannot be determined until analyses are complete.

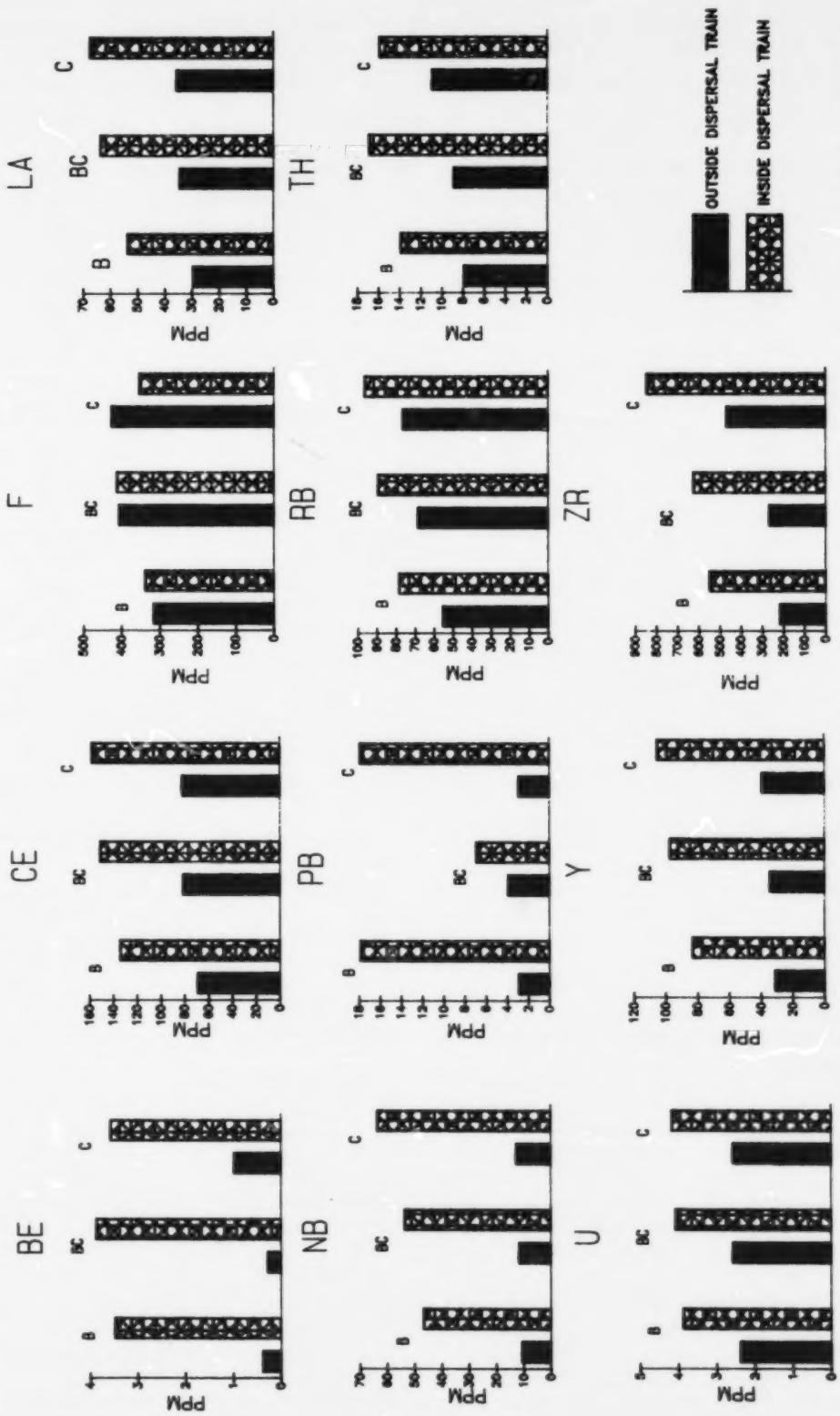


Figure 20. *Comparison of trace-element geochemistry between individual soil horizons inside the Strange Lake dispersal train, with background values from soils over the gneissic terrane outside the dispersal train.*

Table 7: Background geochemical values of till overlying the gneissic terrane to the north of the Strange Lake dispersal train. Values in ppm unless otherwise stated. Analyses performed on the finer than 63 μm fraction of soil horizons developed in till

	B Horizon				BC Horizon				C Horizon			
	Median	Max	Min	n	Median	Max	Min	n	Median	Max	Min	n
Ba	768	999	616	51	821	978	661	46	844	1090	681	26
Be	0.4	1.2	0.1	53	0.3	1.9	0.2	46	1.0	1.0	0.2	26
Ce	70	98	57	37	82	127	59	28	83	140	74	26
Co	3	10	1	53	4	12	2	46	4	14	2	26
Cr	45	73	27	51	42	72	29	46	43	80	30	26
Cu	9	37	3	53	16	33	6	46	18	34	5	26
F	319	581	169	53	409	645	204	46	429	734	275	26
Fe%	1.05	1.84	0.44	53	0.99	1.75	0.55	46	0.86	2.15	0.56	26
Ga	15	19	11	14	17	72	12	18	16	81	13	17
La	30	46	22	51	35	61	23	46	36	58	24	26
Li	8	13	4	53	9	16	5	46	9	18	4	26
Mn	68	212	35	53	83	150	0	46	85	239	0	26
Nb	11	28	8	51	12	35	8	46	13	17	10	26
Ni	6	17	2	53	8	28	3	46	8	21	2	26
Pb	3	10	1	53	4	8	1	46	3	33	1	26
Rb	56	95	35	51	69	101	37	46	77	93	55	26
Sr	276	327	237	51	294	348	262	46	299	380	175	26
Th	8	20	1	51	9	25	0	46	11	26	0	26
U	2.4	4.1	1.6	53	2.6	3.9	1.4	46	2.6	6	1.8	26
V	63	106	40	51	62	107	42	46	69	108	39	26
Y	32	47	22	51	35	61	25	46	40	51	32	26
Zn	16	37	8	53	20	36	8	46	21	40	9	26
Zr	222	703	147	51	271	736	136	46	473	613	173	26

Vertical Changes in Geochemistry

Apart from shallow hand-dug test pits, few vertical exposures of glacigenic material exist in the Strange Lake area. One of these occurs in the Iron Ore Company of Canada trench that exposes exotic-rich bedrock. Two till units outcrop at this site (see Figure 7). A diamicton interpreted as lodgement till overlies the western margin of exotic-rich mineralized bedrock. This lower unit has elevated values for most deposit-related element concentrations (Be, Pb, Th, U, Y, Zr) relative to an overlying unit interpreted as basal melt-out till. Ore-element (Be, Pb, Th, U, Y) concentrations are commonly twice that of the overlying unit, and in the case of yttrium, are up to eight times greater.

In the sidewalls of a meltwater channel located approximately 3 km down-ice of the deposit, a 5.5 m-exposure of glacigenic sediment was examined. The section is composed, from the base, of a 135-cm compacted, red, medium-sand diamicton, containing small (1- to 3-cm thick and 1- to 5-cm long) lenses of fine sand, and greater than 20 percent by volume angular to subangular clasts (mostly peralkaline granites); an 18-cm unit that contains fine sand and silt laminations; 180 cm of diamicton having a similar character to that overlying it but which is more compacted and has a crumbly structure; 200 cm of a grey, slightly compacted, fine sand, diamicton containing small (1- to 3-cm thick and 1- to 5-cm long) lenses of medium- to fine-sand and subrounded to subangular clasts having fine sand to silt coatings; and a surface capping of 19 cm of podzolic soil development. The upper 4 m of diamicton is interpreted to be a basal melt-out till, similar to that exposed in the IOCC trench. It is geochemically uniform, with little variations noted for deposit-related elements (Figure 21). Other, more mobile elements (e.g., Cu, F and Zn) show a down-profile increase in values. The red till is likely basal till of local provenance and may be of either a melt-out or lodgement origin. The red colour is probably derived from red, riebeckite-rich, exotic peralkaline granite bedrock, noted 50 m north of the site. Geochemically, the sediment has elevated (commonly ten times that of the overlying unit) peralkaline granite-related element concentrations (Figure 21), indicating local derivation.

The lack of sufficiently thick exposures of glacigenic sediment means that few conclusions, concerning changes in stratigraphic geochemistry, can be drawn. It is clear that a change in depositional environment commonly correlates with a considerable shift in geochemical values, and that a downward change may reflect the shorter distance of transport for sediment in the lower stratigraphic units. Distinct geochemical breaks mark a change in depositional

Table 8: Geochemical values of till within the Strange Lake dispersal train. Values in ppm unless otherwise stated. Analyses performed on the finer than 63 μm fraction of soil horizons developed on till. (Highlighted elements are anomalous within the Strange Lake deposit.)

	B Horizon				BC Horizon				C Horizon			
	Median	Max	Min	n	Median	Max	Min	n	Median	Max	Min	n
Ba	744	902	604	66	821	919	659	47	840	987	731	29
Be	3.5	13.8	0.4	66	3.9	9.4	1.1	47	3.6	6.4	1.3	29
Ce	135	255	63	60	152	266	100	47	159	220	134	29
Co	2	4	1	66	2	3	1	47	2	6	1	29
Cr	29	82	19	66	28	56	16	47	25	57	18	29
Cu	5	14	3	66	7	13	3	47	8	14	4	29
F	341	797	169	66	415	734	68	47	356	785	282	29
Fe%	0.83	2.11	0.53	66	0.72	1.21	0.48	47	0.66	1.14	0.49	29
Ga	21	42	14	6	28	73	16	13	21	63	11	19
La	54	109	26	66	64	124	41	47	68	124	48	29
Li	6	19	3	66	7	18	3	47	6	15	4	29
Mn	58	139	27	66	67	114	26	47	64	135	38	29
Nb	47	91	11	66	54	93	18	47	64	106	21	29
Ni	3	6	1	66	3	45	1	47	3	16	2	29
Pb	18	126	6	66	17	77	7	47	18	90	9	29
Rb	79	102	39	66	90	117	77	47	97	131	78	29
Sr	243	352	197	66	263	298	207	47	267	360	238	29
Th	14	37	1	66	17	90	4	47	16	42	2	29
U	3.9	6.1	0.5	66	4.1	8.6	2.6	47	4.2	6.3	3.0	29
V	36	72	27	66	37	53	24	47	39	61	30	29
Y	84	183	27	66	98	235	52	47	106	181	61	29
Zn	16	51	6	66	21	232	7	47	19	44	11	29
Zr	555	1121	215	66	631	1601	267	47	851	2011	474	29

environment (Figures 7 and 21). As a consequence, it is also possible that surface sampling at such a site would fail to reveal evidence of mineralization at the base. Further study, preferably using drilling and trenching, is needed to determine the processes of down-ice dispersal through a till sheet in the Strange Lake area.

Mudboil Sampling

The use of mudboils as a sampling medium has been tested extensively (Klassen and Shilts, 1977; Shilts, 1972, 1974; DiLabio, 1979). Mudboils provide good sample control because they occur almost exclusively on till, and are common in areas of permafrost.

Mudboils are circular to elongate forms, composed of bare patches of soil 1 to 3 m in diameter. They are probably formed through the build-up of cryostatic pressure and its subsequent release by upward movement of wet, fine sediment, which is injected into the surface layer. The diapiric centre of a mudboil is considered to be equivalent to the C horizon of a soil profile. Any existing soil profile is destroyed and re-incorporated into the mudboil to be reworked and extruded again at the surface in a continuously cyclical process. This repeated exposure to oxidation breaks down the labile minerals (sulphides, carbonates, etc.), leaving stable minerals and trace elements absorbed on fine grained phases (Shilts, 1972).

The geochemical expression of till may differ between the mudboil and C horizon samples, hence sampling has to be consistent. Within the Strange Lake area, drainage and slope differences led to an irregular distribution of mudboils and the complete dependence on mudboil samples was not possible. However, is it possible to use data derived from mudboil samples with data derived from a normal, undisturbed soil profile? To test this, mudboil samples were collected from a depth of about 50 cm from 206 sites, but in only 17 cases were the mudboils within 500 m of soil-profile samples. These data are presented in Table 9 and Figure 22.

A non-parametric two-sample median test on mudboil and soil data showed that a statistically significant difference only exists for Ba, Fe, Mn and Zn, with enhanced values within mudboils. This finding is in marked contrast and opposite to that proposed by Shilts (1972). For all other elements no significant difference was recorded.

The conclusions from this comparison are:

1) that values for Ba, Zn and those of secondary weathering phases (Fe and Mn) are enhanced within the mudboils compared to adjacent soil profiles. Barium, Fe, Mn and Zn values are, on average, 1.15 times higher in mudboils, possibly reflecting accelerated weathering in the mudboils.

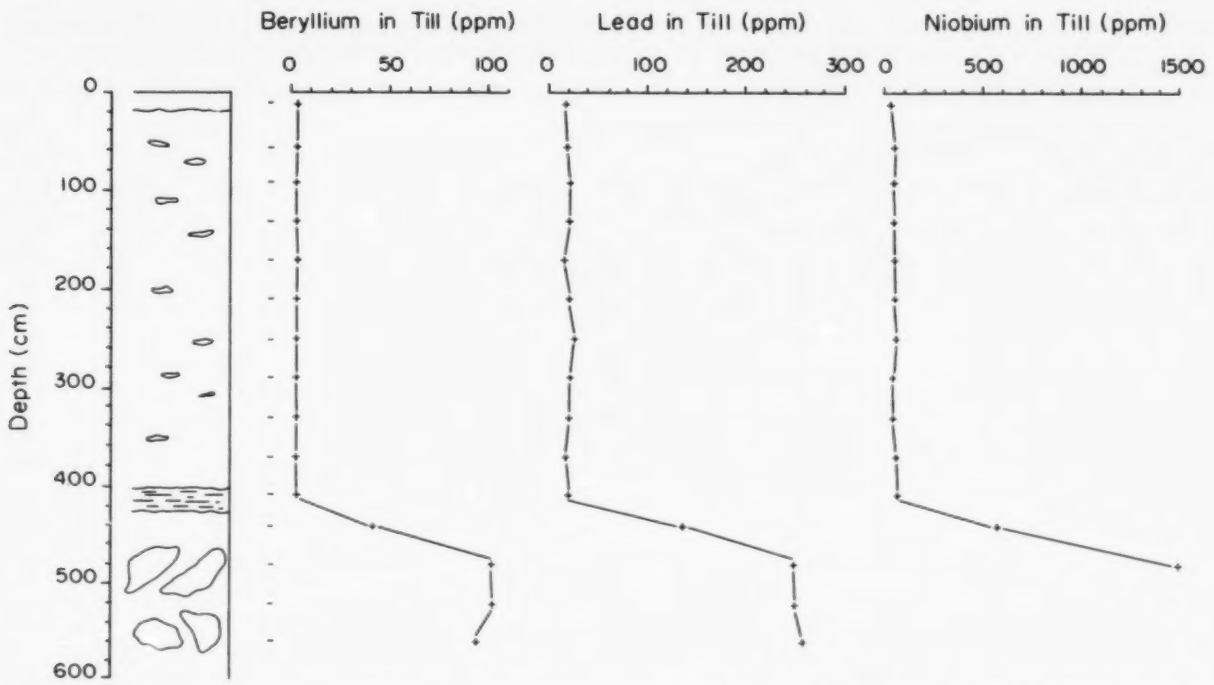


Figure 21. *Trace-element geochemistry of tills exposed within the sidewalls of a meltwater channel, 3 km down-ice of the Strange Lake deposit.*

Table 9: Comparison of trace-element geochemistry between mudboils and adjacent soil horizons developed on till. Values in ppm unless otherwise stated. Analyses performed on the finer than 63 μm fraction

	Till from mudboils				C horizon of soil developed on till				Mudboil/soil ratio
	Median	Max	Min	n	Median	Max	Min	n	Probability[1]
Ba	860	1001	759	16	819	890	681	20	.0409
Be	1.0	5.5	0.6	17	1.06	6.7	0.1	20	.8836
Ce	125	173	83	8	110	276	79	16	.6668
Co	3	8	1	17	2	14	1	20	.1935
Cr	31	53	17	16	29	80	19	20	.7312
Cu	10	44	3	17	8	32	3	20	.4066
F	415	657	319	17	377	734	267	20	.4003
Fe(%)	0.85	2.02	0.5	17	0.72	2.15	0.59	20	**.0282**
Ga	17	22	12	8	19	28	15	4	.4444
La	49	105	39	16	51	100	33	20	.7312
Li	8	18	4	17	7	18	4	20	.2406
Mn	84	175	51	17	73	147	37	20	**.0280**
Nb	22	91	12	16	21	90	13	20	.9838
Ni	4	22	1	17	4	21	1	20	.6289
Pb	7	52	3	17	7	72	3	20	.8836
Rb	83	127	62	16	81	111	63	20	.7312
Sr	278	304	243	16	272	301	235	20	.3026
Th	14	29	7	16	12	25	6	20	.1749
U	3.5	6	1.2	15	3.5	6.4	2.3	20	.9232
V	45	108	35	16	40	96	31	20	.1749
Y	56	163	33	16	59	175	39	20	.7312
Zn	22	45	12	17	18	46	8	20	**.0282**
Zr	533	1807	180	16	352	1304	215	20	.3026

[1] Indicates probability of randomness. Highlighted values are statistically significantly different at the 95% confidence level.

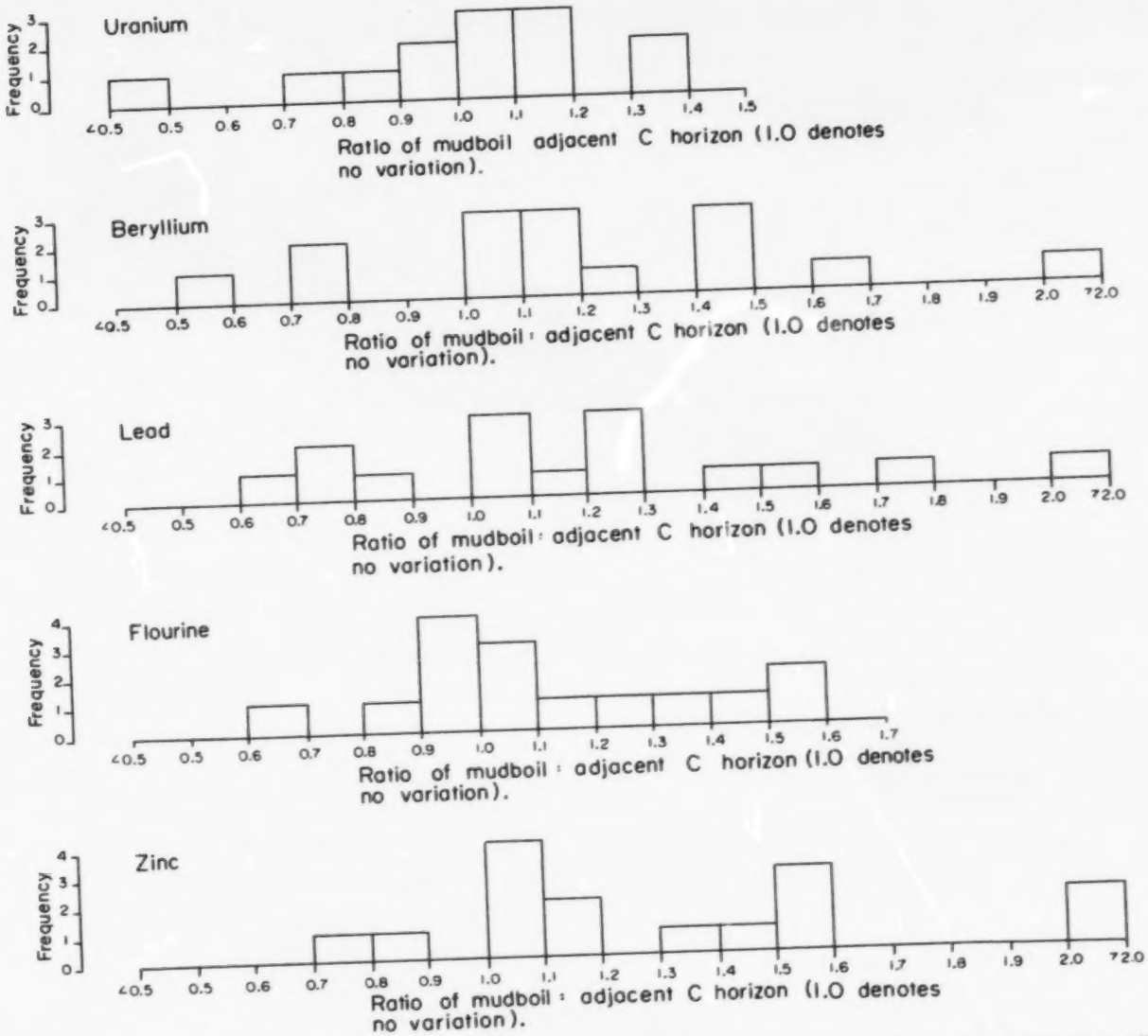


Figure 22. *Comparison of trace-element geochemistry between mudboils and adjacent soil-horizons developed on till.*

2) that the concentration of all other elements show no significant variation between till in mudboils and in the C horizon of soil profiles, and

3) because stable elements are the main interest in the study area it is a valid approach to include mudboil and soil profile values together in a regional sampling program (e.g., sample spacing greater than 500 m).

Geochemistry of Glacigenic Sediments

Of the 1081 samples collected across the Strange Lake area, 90 were from non-till materials. Combining geochemical data from sediment deposited in different depositional environments has long been recognized as an undesirable practice, because the geochemical signature of one environment is commonly different from that of another. Shilts (1972) demonstrated this for esker and adjacent till samples in the Kaminak Lake area, District of Keewatin. He also showed that from analysis of the finer than 0.063 mm fraction, the background concentrations of trace metals were 6 to 10 times higher in eskers than in adjacent till. Similar results are found in this study (Figure 23). A combination of esker and till data shows that most esker data lies in the top 5 percent of values. Inclusion of esker data deflects the dispersal train northward when compared to results generated from till data (Figure 24) and defines peak values at locations unrelated to the mineralization in bedrock. Shilts (1972) explained the difference between esker and adjacent till values by recognizing that most of the finer than 0.063 mm fraction in an esker environment is secondary weathering products

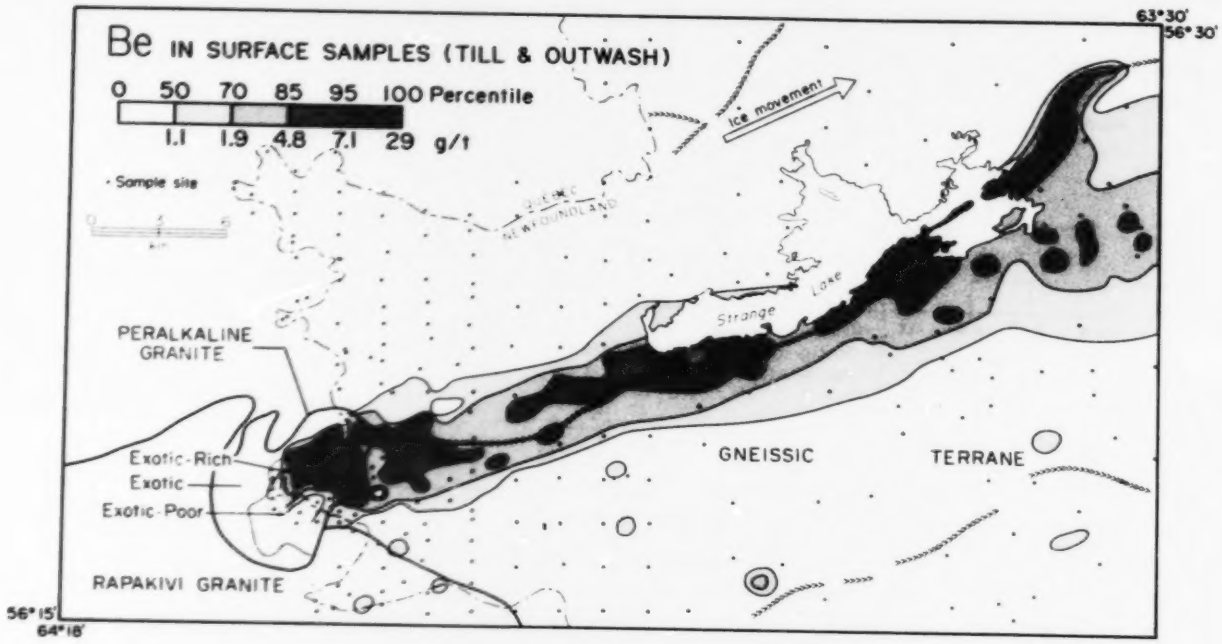


Figure 23. *Beryllium concentration in surface samples (till and outwash) at Strange Lake.*

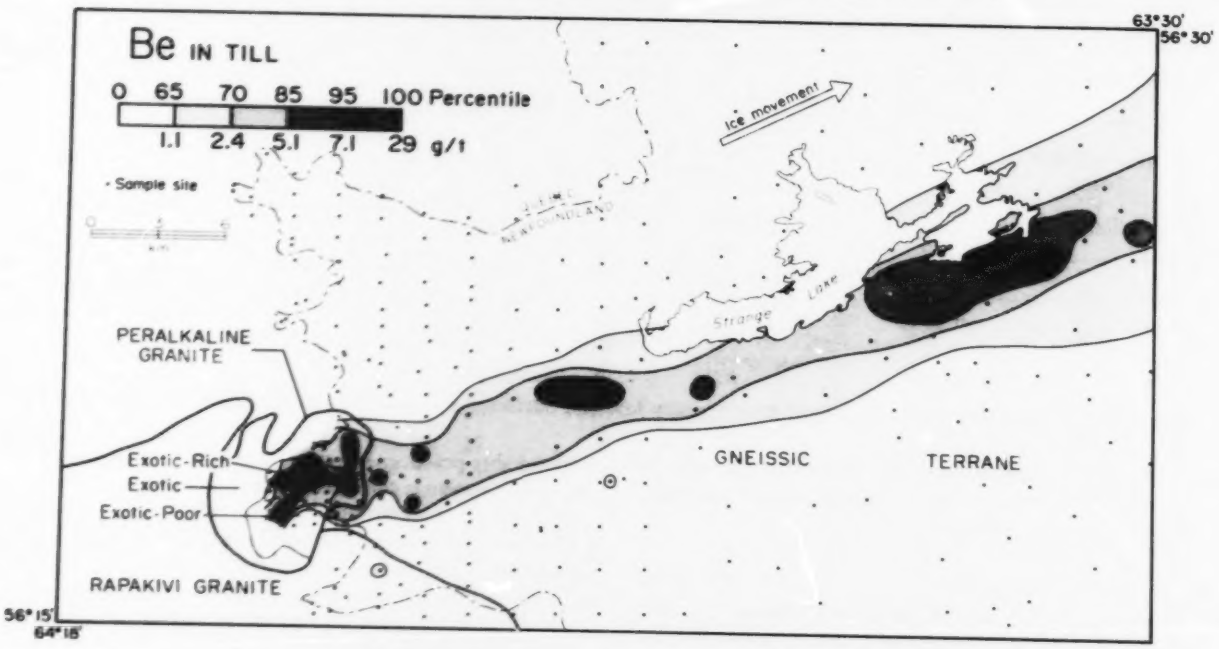


Figure 24. *Map showing the distribution of Beryllium concentrations in till in the Strange Lake area.*

that are trace-metal scavengers, whereas most fine grained material in till is of primary origin.

Eskers have been successfully used in isolation for exploration geochemistry (Lee, 1965, 1968). However, there are limitations. These limitations are not only related to the contrasting geochemical response between eskers and till, but more fundamentally because eskers do not always occur near or downstream from mineralization. Because of these factors, only till samples are considered in the following discussion.

Table 10: Pearson correlation matrix for till data in the Strange Lake area

.17 Indicates .001 sig. (99.9% Confidence Level)
n=904

	Cu	Pb	Zn	Co	Ni	Mn	Fe	Be	F	U	Y	V	Li	Th	Rb	Sr	Zr	Nb	Ga	La	Ba	Ce	Cr
Cu	1.00																						
Pb	**-.23**	1.00																					
Zn	.52	**.44**	1.00																				
Co	**.82**	**-.31**	**.49**	1.00																			
Ni	**.81**	**-.34**	**.45**	**.84**	1.00																		
Mn	**.61**	.04	**.68**	**.67**	**.59**	1.00																	
Fe	**.43**	-.07	**.42**	**.53**	**.50**	**.44**	1.00																
Be	**-.14**	**.82**	**.41**	**-.25**	**-.28**	-.04	**-.18**	1.00															
F	**.31**	**.34**	**.66**	**.29**	**.19**	**.48**	**.26**	**.28**	1.00														
U	-.05	**.76**	**.53**	**-.15**	**-.20**	**.18**	-.05	**.72**	**.46**	1.00													
Y	-.01	**.85**	**.61**	**-.22**	**-.26**	-.13	-.03	**.78**	**.46**	**.84**	1.00												
V	**.34**	**-.51**	.02	**.55**	**.57**	**.26**	**.37**	**-.44**	.04	**-.36**	**-.53**	1.00											
Li	**.56**	**.14**	**.80**	**.62**	**.57**	**.71**	**.56**	.10	**.57**	**.29**	**.27**	**.23**	1.00										
Th	.02	**.58**	**.55**	-.08	-.11	.16	.18	**.56**	**.38**	**.63**	**.59**	**-.20**	**.33**	1.00									
Rb	.08	**.65**	**.64**	-.02	-.09	**.25**	-.07	**.65**	**.48**	**.72**	**.68**	**-.32**	**.34**	**.62**	1.00								
Sr	.12	**-.17**	.04	.16	.15	.04	.08	**-.20**	.07	**-.18**	-.13	.18	.04	-.15	-.16	1.00							
Zr	**-.27**	**.71**	**.25**	**-.40**	**-.45**	-.01	-.16	**.53**	**.36**	**.65**	**.74**	**-.51**	-.01	**.38**	**.57**	**.17**	1.00						
Nb	-.10	**.88**	**.48**	**-.29**	**-.31**	-.09	-.06	**.79**	**.37**	**.77**	**.91**	**-.51**	.14	**.50**	**.70**	-.15	**.84**	1.00					
Ga	.13	**.21**	-.12	-.03	.03	.12	.02	-.08	-.03	.12	**.26**	**-.21**	.06	-.07	-.07	.03	**.26**	**.31**	1.00				
La	-.11	**.80**	**.66**	-.13	-.15	**.28**	.16	**.71**	**.54**	**.82**	**.85**	**-.39**	**.37**	**.55**	**.70**	-.12	**.68**	**.83**	**.24**	1.00			
Ba	-.01	.00	.13	.10	.04	.06	.08	.02	.14	.04	-.10	**.21**	.05	.01	.07	.07	**-.19**	-.09	-.13	.01	1.00		
Ce	-.01	**.62**	**.60**	-.09	-.15	**.28**	**.18**	**.57**	**.57**	**.66**	**.54**	-.04	**.36**	**.57**	**.62**	-.16	**.42**	**.52**	-.12	**.67**	**.21**	1.00	
Cr	**.52**	**.64**	-.09	**.61**	**.67**	**.29**	**.34**	**-.54**	-.14	**-.50**	**-.54**	.04	**.26**	**-.34**	**-.51**	.14	**-.62**	**-.60**	.02	**-.48**	-.11	**-.45**	1.00

Note: All values are logged data.

The geochemical dispersal patterns from the Strange Lake deposit have been described in detail by McConnell and Batterson (1987) and are summarized below.

In total, 23 single element dispersal maps were produced. Randomly selected samples from the uppermost C horizon and mudboils were used in the analysis and the data have been arbitrarily divided into intervals at the 50th, 70th, 85th and 95th percentiles. The dispersal patterns vary widely between elements. A group of elements including Be, Pb, U, Th, Y and Zr highlight the area of mineralization whereas others (e.g., Co, Ni and Cu) reflect either the gneissic terrane to the north or dispersion from the adamellites to the south. Clearly then, several elemental associations occur within the geochemical data.

In order to more fully understand the inter-elemental associations, a Pearson correlation coefficient matrix was generated (Table 10). The table shows that elements having strong correlations (greater than 0.8) fall neatly into two groups. The first group consists of Co-Ni-Cu, which likely reflects a mafic component of the gneissic terrane. The second group is of lithophile elements associated with the ore elements of the Strange Lake deposit (Be-La-Nb-Pb-U-Y-Zr). Analysis of this second group of elements shows that the patterns of dispersal are broadly similar (e.g., Figures 24 and 25). The highest values are clustered over the peralkaline granite and the mineralized zone in particular, and the dispersal train extends parallel to ice movement as interpreted from ice-flow direction indicators. The train is ribbon-shaped, although some fanning occurs beyond 30 km down-ice. The train is clearly delineated for at least 40 km down-ice of the deposit. The geochemical contrast between the peralkaline-related dispersal train and local background over the gneissic terrane to the north, is sharp. The difference between the peralkaline granite dispersal pattern and that of the adamellite is clear, although less pronounced. This is a reflection of more elevated ore-related element values within the adamellite than in the gneissic terrane.

The geochemical dispersal pattern has a separate anomaly and series of anomalies in all deposit-related elements, about 15 km and 25 km respectively, down-ice of the deposit. Regional geology maps show that these areas are underlain by Archean gneisses and are not related to any suitable mineralization (Ryan *et al.*, 1988). These anomalies, therefore, correspond to either unknown mineralization or, more likely, are related to the mode of till deposition and are associated with the peralkaline granite. Of note is the fact that the anomalies correspond to topographic highs.

Two elements that have abnormally high concentrations in the peralkaline granite, and might be expected to be effective indicator elements in till, are zinc and fluorine. Maps of their distribution show only moderate correlation with the peralkaline granite and its dispersal train, and probably result from the presence of several areas of till overlying and down-ice from gneissic terrane to the north, which also have high concentrations of Zn and F. High F levels are also found over and down-ice from the adamellite, which Currie (1985) notes to be fluorite-bearing.

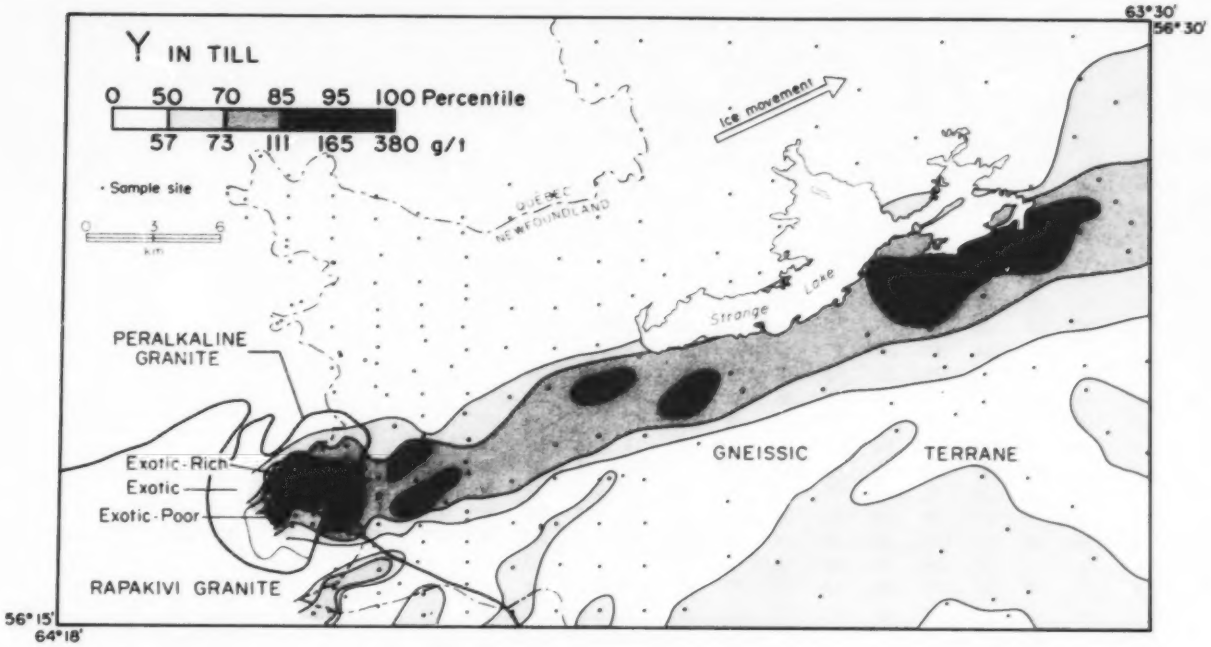


Figure 25. *Map showing the distribution of Yttrium concentrations in till in the Strange Lake area.*

It is apparent from the single element dispersal maps that the geochemical signature of the Strange Lake deposit can be well illustrated without the application of a detailed statistical approach. However, a non-statistical treatment of the data does not adequately delineate the elemental associations and therefore, principal component analysis was applied. Principal component analysis takes advantage of the numerous elements analyzed and of the mutual correlations of elements associated with the peralkaline granite; it also smoothes many insignificant fluctuations in individual element patterns. The objective is to reduce the large volume of data to a series of factors (the inter-elemental associations). The method is, in many ways, trial and error, and employs numerous applications of the principal component approach (see Nie *et al.*, 1975 for details), to determine that which best describes the variation within the data. With the Strange Lake till data, the most satisfactory resolution of the data was from a three-factor model attained by a varimax rotation. Factor one was similar in all models tried. The most significant variables in each factor, and a geological/geochemical interpretation are given in Table 11. The variables are listed in order of decreasing contribution to the factor. The elements in factor one having positive loadings are those particularly associated with the peralkaline granite. The pattern of the peralkaline granite train as displayed by factor-one scores, which are expressed in standard deviation units (Figure 26), has a focus overlying the Strange Lake deposit. Values decrease more smoothly in a down-ice direction than is the case with yttrium (Figure 25). Contrast of the peralkaline granite dispersal train, relative to the adamellite-related train in the southeast quadrant, is also more pronounced for factor-one score data than for yttrium.

A cumulative frequency curve for factor-one scores calculated from till data is shown in Figure 27. Using the method of Sinclair (1974), the data are divided at the inflection point into two populations—an upper 15 percent mainly composed of till derived from the peralkaline granite and a lower 85 percent, composed of till derived from the gneiss and adamellites, and are here considered as the background population. These two populations are used to identify and compare indicator elements in the till which are diagnostic of the deposit. Because of overlapping ranges, a complete separation of the two populations is impossible but it is minimized by arbitrarily considering only the central 80 percent of the data in each population. These are shown in Figure 27 as the peralkaline and background sub-ranges. Due to overlapping populations, such a separation results in the top 2.5 percent of the background samples being misclassified as peralkaline (6 of 42 samples) and the bottom 2 percent of the peralkaline population being misclassified as background (1 of 172 samples).

The geometric mean and the mean $\pm$ two standard deviations range for most elements were calculated for each population sub-range defined above. These are plotted in Figure 28. Of the 23 pairs of elements plotted, ten are diagnostic of the peralkaline granite and may be subdivided into two groups. The first comprises elements that have both good separation of means and little overlap of ranges; they should prove to be the most useful when studying till geochemistry. Elements in the first group are Be, La, Nb, Pb and Y. A second group consists of elements that have a good separation of means but considerable overlap in ranges are Ce, Rb, Th, U and Zr.

Table 11: Three-factor model of principal components analysis of till data

	Variance	Y	Pb	La	Nb	Be	Zr	Rb	U	Ce	Cr	F	Co	Cu	Ni	Li	Fe	Zn	V	Mn	Sr	Ga	Th	Ba
Factor 1 (Peralkaline Granite)	38 %	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	-0.7	0.5												
Factor 2 (Gneiss terrane and Fe–Mn oxides)	20 %												0.8	0.8	0.8	0.8	0.7	0.7	0.6	0.4	0.2			
Factor 3	7 %																					-0.8	0.5	0.4

Note: Only the highest loading for each variable is listed.

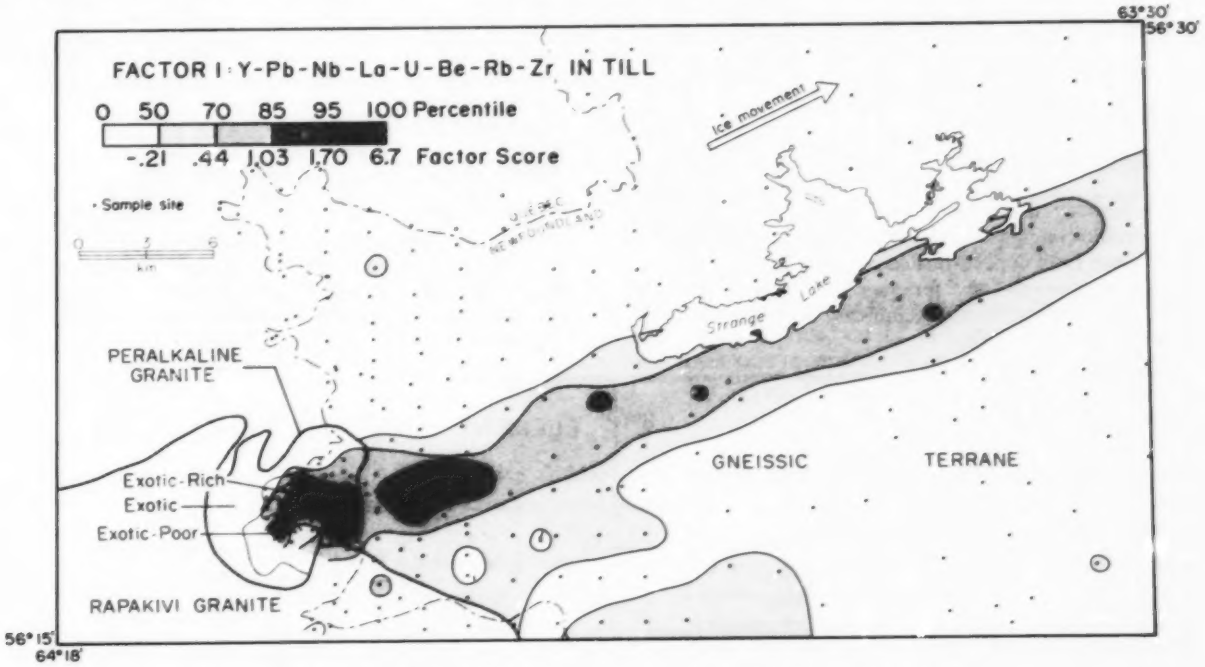


Figure 26. *Map showing factor-one scores in till in the Strange Lake area.*

Dispersal Within Crag-and-Tail Hills

Sampling was done over 17 crag-and-tail hills, both during regional till sampling and as a special project where ramp, crag and parts of the tail were consistently sampled (Figure 29). The aim of this phase of the program was to determine the geochemical/lithological characteristics of these features to determine if the crag-and-tail hills can be sampled with confidence in regional drift-exploration programs and to assess their significance within the Strange Lake deposit dispersal train. At each crag-and-tail feature one C horizon sample was taken from the ramp and the crag, and between 1 and 4 C horizon samples from the tail, depending on the length.

Median geochemical values from each geomorphic component are presented in Table 12 and Figure 30. Data is from all sampled crag-and-tail hills inside the dispersal train from the Strange Lake deposit. Data conforms with expected trends in that values of elements anomalous within the Strange Lake deposit are higher for crag-and-tail hills inside the dispersal train (e.g., Be, Pb, Th, Y) compared to non-complex related elements (e.g., Co, Ni, Zn). Values outside the train are consistent between each geomorphic element of the crag-and-tail hills and approach background values (see Table 7). A non-parametric two-sample median test applied to the data confirms that no statistically significant difference exists between geomorphic components at the 95 percent confidence level. For data within the dispersal train, a non-parametric

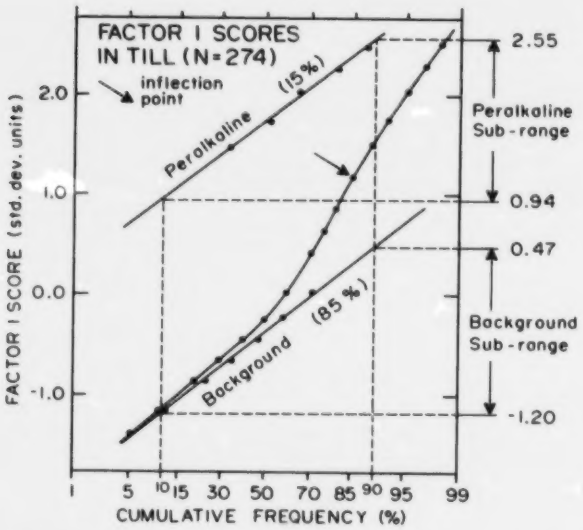


Figure 27. *Cumulative frequency curve for factor-one scores calculated from till data.*

Mann-Whitney test showed that although the crag/ramp geomorphic component consistently recorded higher values for Strange Lake deposit-related elements than the tails, the low sample size (n=1 to 5 for crags and n=9 to 12 for tails) resulted in no statistically significant variation at the 95 percent confidence level.

The suggestion that there are geochemical trends related to the morphology of crag-and-tail hills is strengthened by an examination of individual crag-and-tail hills (Figure 31). For ore-related trace elements (e.g., Be, Pb and U) either the ramp or crag has the highest value and these decrease in a down-ice direction, commonly in an erratic fashion.

An important differentiation can be made between crag-and-tail hills within and those outside the dispersal train (Figure 31). Crag-and-tail hills within the train have the highest values on the ramp or at the crag. However, the tail has an area of low values down-ice of the crag, with increasing values farther down the tail. This relationship is unique to the train and suggests that it is related to the processes of glacial transport and deposition from the Strange Lake deposit.

Clast lithology shows similar patterns. Four major crag-and-tail hills were selected for study, each with tails greater than 1 km in length. The total mineralized clast content (i.e., clasts from the Strange Lake deposit in general with no reference to the phase of mineralization) was considered. In each case, values on the tail showed an increase from near the crag to down-ice of it. In two cases, single sites within 1 km down-ice of the crag had no mineralized clasts. The most westerly crag-and-tail hill within the dispersal train showed that the crag sample had the lowest mineralized clast concentration, a similar pattern to that seen in the geochemical values. However, although the geochemical

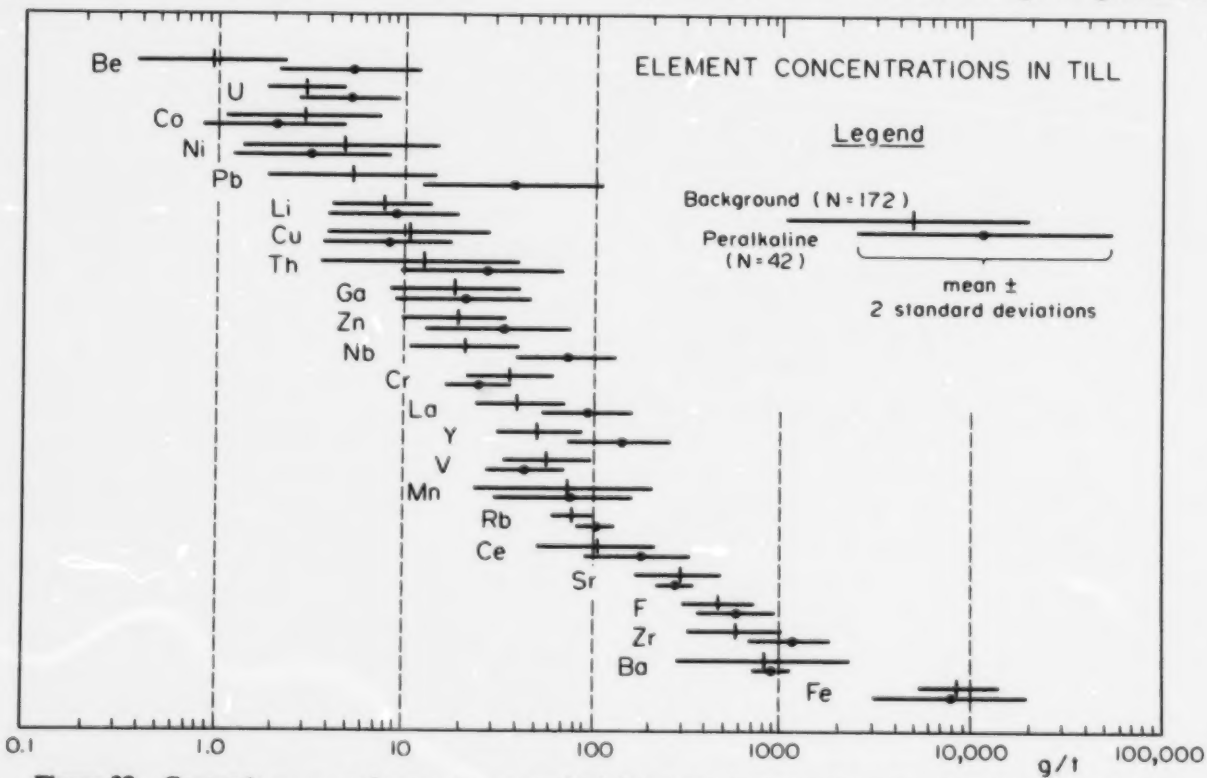


Figure 28. *Geometric mean, and mean ± two standard deviations, for trace-element geochemistry from till data.*

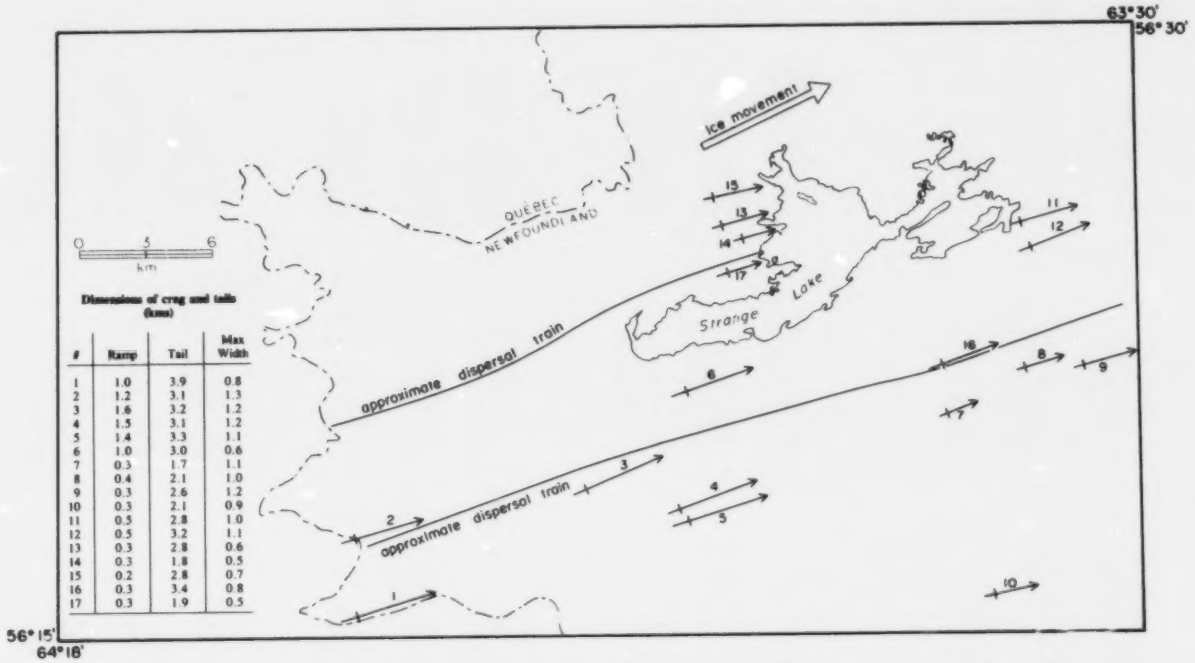


Figure 29. *Map showing the location of crag-and-tail hills sampled in the Strange Lake area.*

Table 12: Median trace-element geochemical values of geomorphic elements of crag-and-tail hills within the Strange Lake dispersal train. Values in ppm unless otherwise stated. Analyses performed on the finer than 63 μm fraction of C soil horizons or mudboils developed on till. (Highlighted elements are anomalous within the Strange Lake deposit)

	Ramp				Crag				Tail			
	Median	Max	Min	n	Median	Max	Min	n	Median	Max	Min	n
Ba	802	974	756	4	825	911	774	4	817	1090	759	12
Be	4.7	5.9	1.0	5	5.6	8.7	0.6	4	3.7	5.2	1.0	12
Ce	180	183	150	3	133	133	133	1	163	197	118	9
Co	3	7	2	5	2	3	2	4	2	4	1	12
Cr	27	29	21	4	26	27	24	4	27	32	24	12
Cu	11	13	9	5	10	16	8	4	10	13	6	12
F	480	657	267	5	429	492	348	4	373	696	298	12
Fe(%)	0.79	3.60	0.70	5	0.80	0.85	0.71	4	0.74	1.24	0.50	12
Ga	16	16	16	1	21	24	18	3	22	23	14	3
La	70	76	59	4	94	107	55	4	63	87	50	12
Li	7	13	6	5	7	8	6	4	6	14	4	12
Mn	75	521	64	5	81	84	65	4	73	110	42	12
Nb	59	70	21	4	67	76	18	4	53	69	19	12
Ni	4	7	3	5	4	6	3	4	4	5	2	12
Pb	18	22	13	5	16	25	7	4	14	23	9	12
Rb	91	101	80	4	99	117	82	4	90	103	82	12
Sr	256	291	245	4	272	287	254	4	276	289	238	12
Th	19	20	14	4	19	23	13	4	16	30	12	12
U	4.2	5.2	3.9	5	4.1	4.7	3.7	4	3.7	5.4	3.5	11
V	38	45	36	4	39	46	37	4	41	63	32	12
Y	103	119	89	4	125	167	62	4	96	123	65	12
Zn	21	42	16	5	21	23	19	4	21	38	12	12
Zr	614	765	511	4	1124	1259	273	4	572	1040	270	12

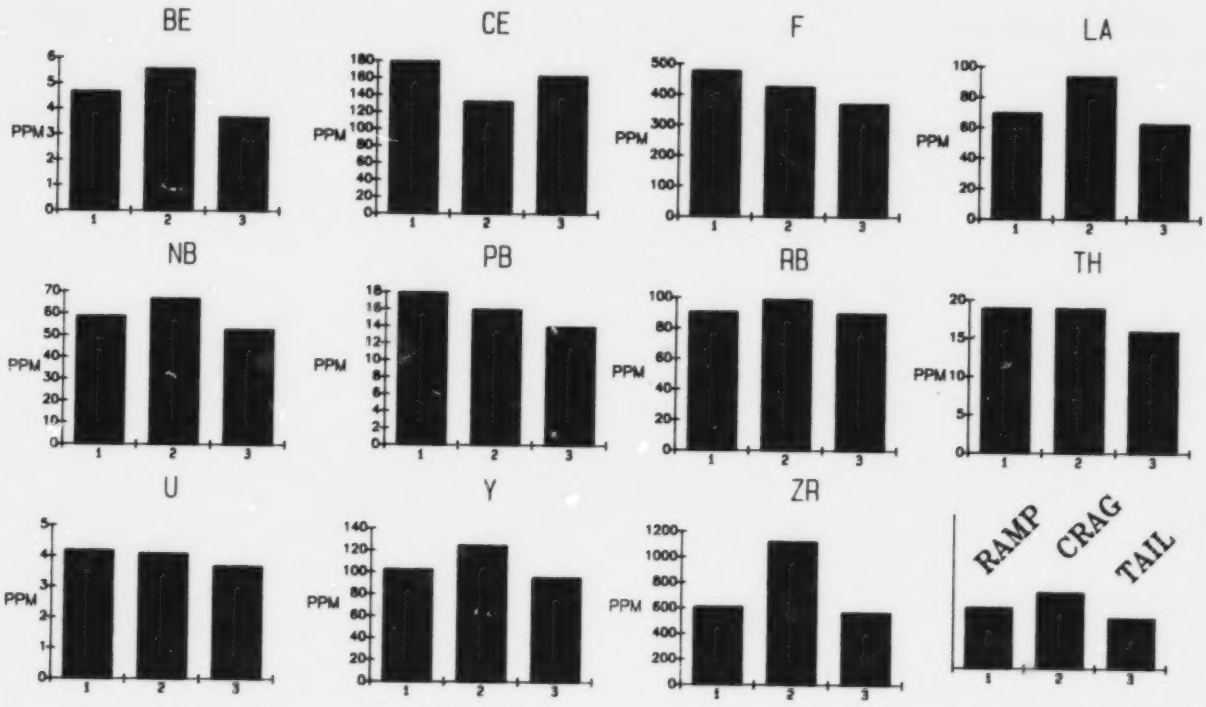


Figure 30. *Median trace-element geochemical values of geomorphic components of crag-and-tail hills within the Strange Lake dispersal train.*

pattern is consistent, a greater sample number would be required to allow statistical significance.

A plausible explanation for these data can be based on the model of crag-and-tail development discussed in an earlier Section, and is illustrated in Figure 32. Prior to glacial advance, resistant rock (commonly amphibolite facies gneiss or quartzofeldspathic gneiss) formed topographic highs. During initial glacial activity, the crag acted as an obstacle to flow and ice was forced to deform around and over the obstacle. On the stoss side of the crag, an area of stranded ice developed as faster moving ice sheared around and over the stalled ice. In the lee of the crag, a hollow or cavity was formed, which gradually closed down-ice in response to internal glacial deformation. The length of this cavity is proportional to the height of the crag and ice-flow velocity.

Erosion occured as ice flowed round the crag as shown by numerous striae and grooves. Deposition of material from the crag occured within a short distance of it, the distance being a function of the width of the crag along the ice-flow path (Shilts, 1976; see Figure 10). In the case of the Strange Lake crags, the source width is only several-hundred metres and the area of maximum deposition from erosion of the crag is likely within several-hundred metres. Therefore, the maximum amount of local debris within the tail would be at sites close to the crag. Consequently, the area immediately down-ice of a non-mineralized crag within the Strange Lake dispersal train will be diluted by local debris and, therefore, will have low concentrations of peralkaline granite clasts and low trace-element levels compared to sites farther down the tail or on the ramp. On the up-ice side of the crag, material will continue to be added to the stagnant, debris-rich ice, perhaps partially through a lodgement process.

The crag itself is an area of net erosion. Sampling near the crag was commonly within till pockets on bedrock, on, or immediately down-ice of, the crag. It is likely this represents material deposited subglacially in the lee of the crag when debris-rich ice came into contact with the crag. This material was probably derived from up-ice of the crag. In some cases (e.g., crag-and-tail 2; Figure 29), geochemical and lithological values at the crag are the lowest found over the feature. In such cases, the sample was from material derived mainly from the crag, which has consequently diluted any component derived from the Strange Lake deposit.

This study of crag-and-tail hills leads to the following conclusions.

1) Sampling over these landforms shows that sediment at the crag commonly produces the highest values. This conclusion is based on the study of 7 crag-and-tail hills within the dispersal train, which show that for 6 out of 7 cases for trace elements related to the Strange Lake deposit, the crag is the most anomalous. Till ramps on the up-ice side of crags have values similar to, or greater than, those at the crags. Ten crag-and-tail hills

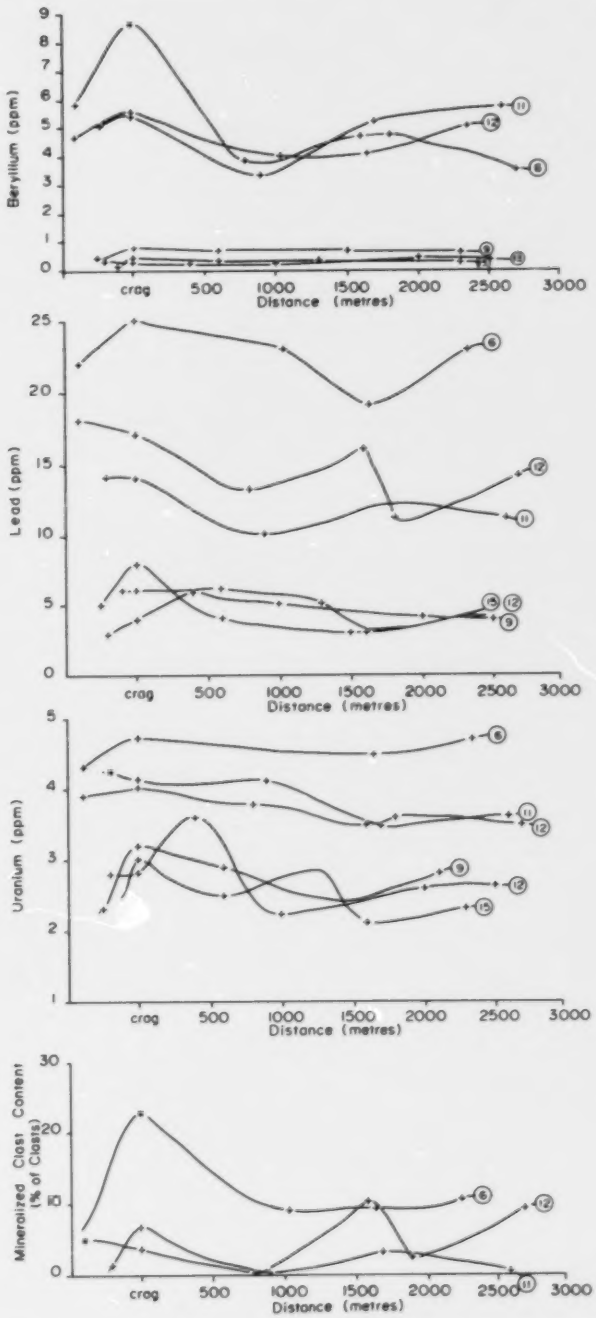


Figure 31. *Trace-element geochemistry along selected crag-and-tail hills within and outside of the Strange Lake dispersal train.*

sampled outside the train showed no geochemical variation along their length.

2) Tails down-ice of crags generally produce slightly lower trace-element values in a ramp-crag-tail comparison. For the REE suite, in the 6 sites where valid comparisons can be made, no geomorphic component preference is noted.

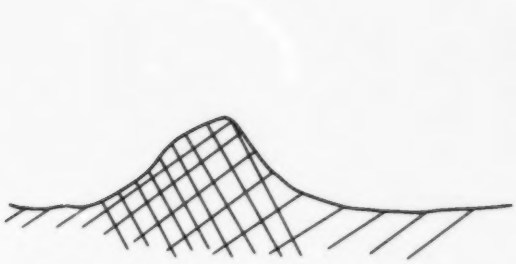
3) It is apparent from this study that there is a clear and well defined geochemical difference between the sediment of different geomorphic components within a crag-and-tail hill. From an exploration viewpoint it suggests that in the Strange Lake area at least, it is preferable for consistency and ease of sampling that samples be taken at, or near, the crag.

Glacial Transport Within the Strange Lake Area

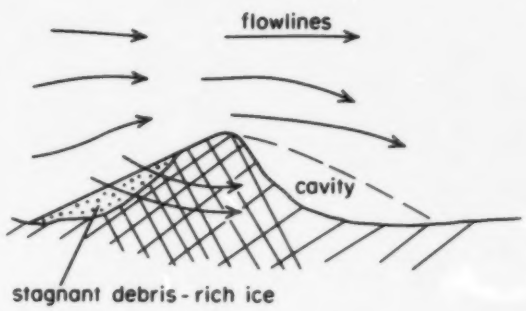
The lithological and geochemical properties of the till are the result of a complex response to glacial dispersal from the Strange Lake deposit. A comparison shows that the trends are similar in all sampled media (Figure 33). Viewed individually, the explanations provided for these trends are speculative. However, they provide an insight into the modes of transportation and deposition within the area.

Comparison of the till pebble lithology and trace-element concentrations along a transect oriented parallel to glacial flow shows corresponding highs. All the identified anomalies occur down-ice of the deposit, within the dispersal train. It has been shown from consideration of both geochemical and clast data that these anomalies commonly correspond to topographic highs, notably crag-and-tail hills. The well defined anomalies within the Strange Lake dispersal train (e.g., 22 percent mineralized clast content of surface clasts at 22 km down-ice of source) suggest long transport distances for much of the sediment. From the extent of the dispersal train, it is unlikely that glacial material was transported in the basal layers of the ice and deposited as lodgement tills because these are characteristically short-transported. Instead, it is likely that material was transported passively in the ice near the base but not in contact with the substrate. The thin lodgement tills in the area, and the widespread occurrence of thick glacial diamicton, which has characteristics of a basal melt-out till, suggest that much material was transported englacially by the Laurentide ice sheet in this area.

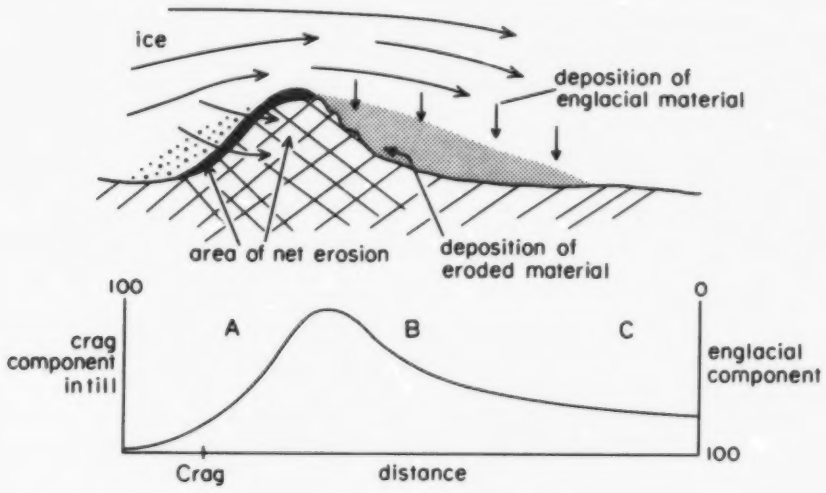
The amount of erosion from the Strange Lake deposit and the spatial distribution of erosion is unknown. Data from diamond drilling indicates that overburden thickness commonly in excess of 20 m is found on the western flanks of the deposit, although whether this represents a single depositional event is not known. Nevertheless, from the amount of dispersed material, it is likely that extensive erosion of the deposit has occurred. The deposit has a surface vertical extent of 120 m and if the whole deposit was available for erosion then the englacial debris package within the ice sheet must have been extensive. Bedrock crags intercepted the englacial debris planes and induced deposition, resulting in the formation of crag-and-tail hills. Lowland areas, which have low deposit-related geochemical and lithological values compared to adjacent topographic highs, and are commonly below the elevation of the Strange Lake deposit, received



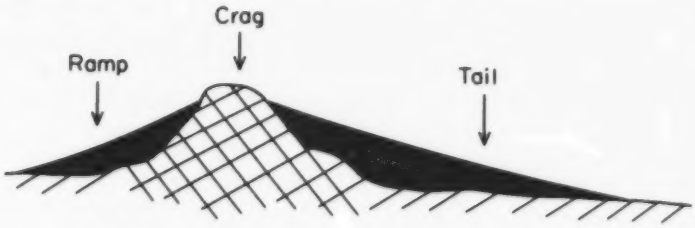
1. Pre-existing terrain



2. Glacier advance



3. Crag and Tail development



4. Post-glacial topography

Figure 32. *A conceptual model illustrating the formation of crag-and-tail hills.*

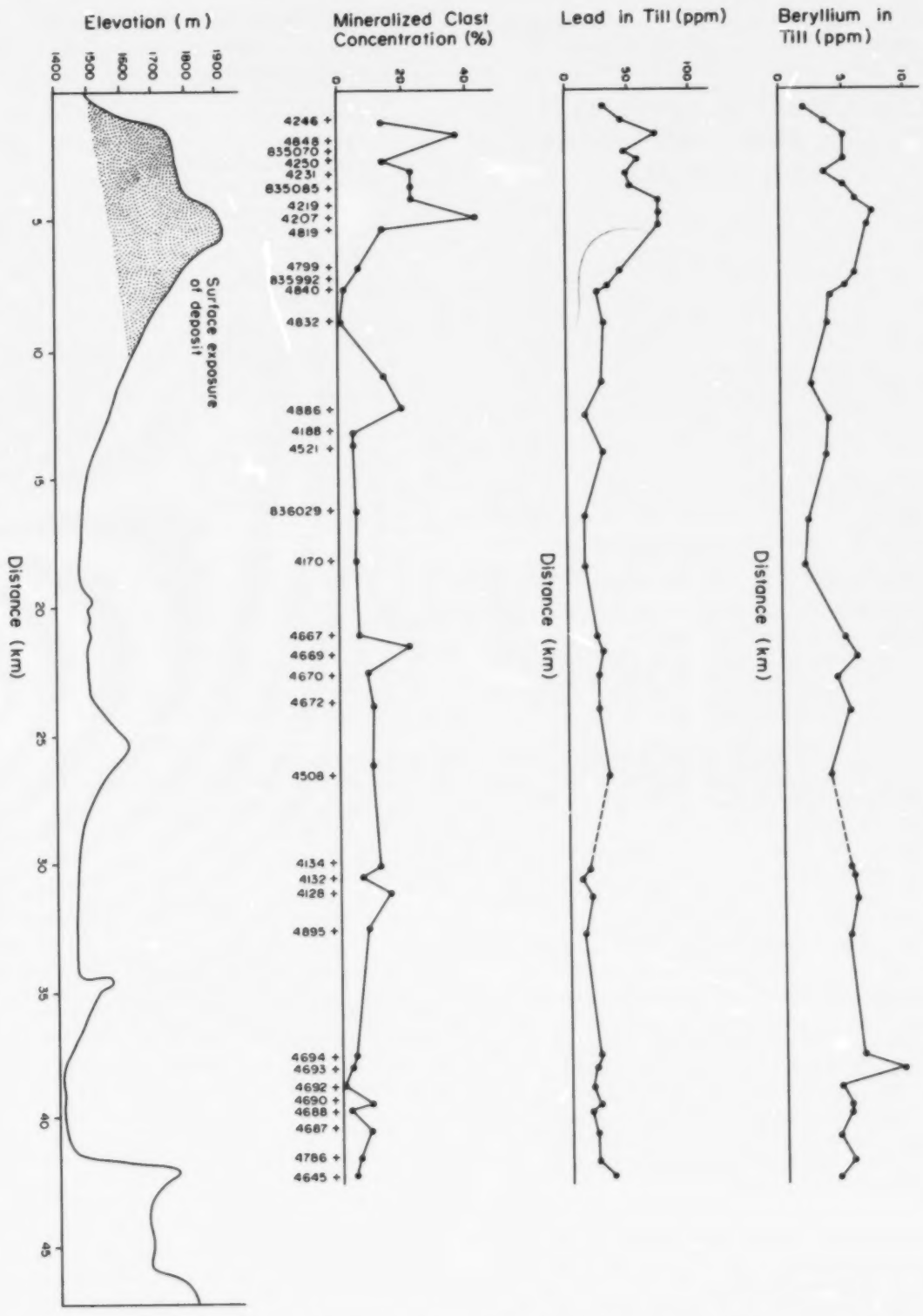


Figure 33. *Longitudinal section through Strange Lake dispersal train parallel to ice flow showing trends in selected trace-element geochemistry values and mineralized clast concentrations.*

material deposited by lodgement or melt-out during the waning phases.

AN EXPLORATION APPROACH TO DISPERSAL FROM THE STRANGE LAKE DEPOSIT

The Strange Lake deposit consists of rock types that are mineralogically and physically distinctive from the surrounding gneiss and adamellite terrane. The deposit has been well defined by diamond drilling and is consequently of known character and extent. Glacial dispersal has been characterized by detailed descriptions of geochemical and lithological trends across the Strange Lake area. A number of important issues generally related to exploration within drift-covered areas have arisen from this study. The major points of the report are summarized below.

1) The Strange Lake area was covered by Late Wisconsinan ice that flowed eastward at a heading of about 070°. Of the major sediment types, till covers about 60 percent of the surface area. Basal melt-out till dominates and this suggests a mainly englacial transportation mode for sediments. Outwash deposits are restricted to several broad, shallow valleys in which well developed esker ridges, commonly reaching 20 m in height are evident. These channels follow the trends of deglaciation in the area.

2) The geochemistry of different soil horizons developed on till, when compared with their individual background values, suggests that either the B or C horizon data produce well defined dispersal patterns; however, the C horizon was preferred because it allowed identification of sediment type. The study also showed that the same background value should not be applied to all soil horizons and that the highest value within a profile is not necessarily the most anomalous.

3) Statistical studies of between-horizon geochemical data shows that for most elements analyzed, there is a significant difference between the B and BC and between the B and C horizons for all elements except Ga, Pb and V. No significant variation occurred between BC and C horizon data, except for Zr. This suggests that geochemical samples representative of the parent material can be taken from any distance below the recognizable B horizon.

4) Mudboils are easy to sample and produce a consistent till sample, but they do not occur uniformly across the Strange Lake area. Comparison of mudboil samples with adjacent C horizon samples suggests that a less than 10 percent variation exists for deposit-related elements and that data may be combined in a regional sampling program.

5) Consistency in sampling of specific glacigenic sediment types is essential for determining accurate dispersal patterns. The well known contrast of esker and till samples is noted. Also of importance, is the difference in values between samples taken near the crag or on the ramp of a crag-and-tail hill compared to adjacent lowlands. The anomalous geochemical and lithological values that were distinguished at certain places along the dispersal train reflect topography rather than adjacent mineralization. In a regional till-sampling survey, and in an area dominated by glacial sediments, the combination of data from hilltops and intervening lowlands may lead to erroneous conclusions regarding the source of anomalies. Similarly, the position of sampling along a crag-and-tail hill is also important. The ramp/crag area consistently has the highest geochemical and lithological values, whereas samples immediately down-ice of the crag consistently have the lowest. The genesis of crag-and-tail features and the fact that most material eroded from the crag was deposited a short distance down-ice of it, thus, diluting any material deposited from an englacial position, are suggested as the reasons for this. It does identify, however, the need for careful sampling programs in areas dominated by these features.

6) The dispersal train defined by both the lithological and geochemical components of the deposit is oriented parallel to glacial flow and has a ribbon-shaped pattern that is very close to the width of the mineralized complex for at least 40 km down-ice.

7) Lithologically, the peralkaline granite can be subdivided into distinct phases (Miller, 1986). The down-ice distribution of boulders and clasts from these phases follow discrete ribbon-shaped dispersal patterns. It suggests that in a terrain, similar to that of Strange Lake and having a similar glacial history, the source of boulders can be clearly found. Also transportation is along well defined, persistent flow lines.

8) The geochemical dispersal train of the Strange Lake deposit is clearly defined through single-element maps. The mineralization is best identified by the elements Be, La, Nb, Pb and Y. A group consisting of Ce, Rb, Th, U and Zr also focused on the deposit, although not as clearly.

9) A sampling pattern of 1 sample per 2.5 km^2 adequately identifies the large dispersal train from the Strange Lake deposit, and is a suitable sample pattern for drift exploration surveys for deposits of this size.

Analysis of dispersal from such unique deposits as the Strange Lake deposit is rare. It provides the opportunity to identify many of the effective exploration techniques for use in drift-covered areas. The results of such a study may be applied to projects in other drift-covered areas, where the bedrock source of the mineralized clasts is presently unknown.

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REFERENCES

Amark, M.
1980: Glacial flutes at Isfallsglaciären, Tarfala, Swedish Lapland. Geologiska Föreningens i Stockholm Förhandlingar, Volume 102, pages 251-259.

Ashley, G.M., Shaw, J. and Smith, N.D. (Editors)
1985: Glacial sedimentary environments. Society of Economic Paleontologists and Mineralogists. Short Course, Number 16, 246 pages.

Banfield, C.C.
1981: The climatic environment of Newfoundland. *In* The Natural Environment of Newfoundland: Past and Present. *Edited by* A.G. Macpherson and J.B. Macpherson. Department of Geography, Memorial University of Newfoundland, pages 83-153.

Barnett, D.M. and Peterson, J.A.
1964: The significance of glacial Lake Naskaupi 2 in the deglaciation of Labrador–Ungava. Canadian Geographer, Volume 8, pages 173-181.

Batterson, M.J., Taylor, D.M. and Vatcher, S.V.
1985: Quaternary mapping and drift exploration in the Strange Lake area, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, pages 4-10.

Bayrock, L.A.
1985: Dr. Lewis Bayrock's method of radioactive boulder tracing and bedrock source identification for a ground moraine environment. *In* Hopfengaertner, F., Assessment Report, Part I. Central Mineral Belt, Labrador. Saarberg Interplan Inc. [13K (166)] 50 pages

Boulton, G.S.
1968: Flow tills and related deposits on some Vestspitsbergen glaciers. Journal of Glaciology, Volume 7, pages 391-412.

1970: On the deposition of subglacial and melt-out tills at the margins of Svalbard glaciers. Journal of Glaciology, Volume 9, pages 231-245.

1976: A genetic classification of tills and criteria for distinguishing tills of different origin. Geografia, Volume 12, pages 65-80.

1978: Boulder shapes and grain-size distributions of debris as indicators of transport paths through a glacier and till genesis. Sedimentology, Volume 25, pages 773-799.

1982: Subglacial processes and the development of glacial bedforms. *In* Research in Glacial, Glaciofluvial and Glacio-lacustrine Systems. Proceedings of the 6th Guelph Symposium on Geomorphology, 1980. *Edited by* R. Davidson-Arnott, W. Nickling, and B.D. Fahey. Geo Books, Norwich, pages 1-32.

Boulton, G.S. and Eyles, N.
1979: Sedimentation by valley glaciers; a model and genetic classification. *In* Moraines and Varves. *Edited by* Schlüchter, Ch., Balkema, pages 11-23.

Bowles, J.E.
1978: Engineering properties of soil and their measurement. McGraw Hill, New York.

Canada Soil Survey Committee
1978: The Canadian system of soil classification. Research Branch, Canada Department of Agriculture, Publication 1646, 164 pages.

Clayton, K.M. (Editor)
1972: Slopes. Oliver and Boyd, Edinburgh. 288 pages.

Cooke, H.C.
1929: Studies in the physiography of the Canadian Shield. Part 1. The mature valleys of the Labrador Peninsula. Transactions of the Royal Society of Canada, Volume 23, Section 4, pages 91-120.

Currie, K.L.
1985: An unusual peralkaline granite near Lac Brisson, Quebec-Labrador. *In* Current Research. Geological Survey of Canada, Paper 85-1A, Part A, pages 73-80.

Dawe, R.
1984: Mineral-based opportunities in Newfoundland and Labrador: a presentation to Japanese business representatives in Tokyo, Japan by the Honourable Ron Dawe, Minister, Department of Mines and Energy, Province of Newfoundland, November 4, 1984. [NFLD (1456)]

Denton, G. and Hughes, T.J.
1981: The Last Great Ice Sheets. Wiley Interscience, New York, 484 pages.

DiLabio, R.N.W.
1979: Drift prospecting in uranium and base metal mineralization sites, District of Keewatin, Northwest Territories, Canada. *In* Prospecting in Areas of Glaciated Terrain. Institute of Mining and Metallurgy, Dublin, pages 91-100.

1981: Glacial dispersal of rocks and minerals at the south end of Lac Mistassini, Quebec, with special reference to the Icon dispersal train. Geological Survey of Canada, Bulletin 323, 46 pages.

DiLabio, R.N.W., Rencz, A.N. and Egginton, P.A.
1982: Biogeochemical expression of a classic dispersal train of metalliferous till near Hopetown, Ontario. Canadian Journal of Earth Sciences, Volume 19, pages 2297-2305.

Douglas, M.C.V. and Drummond, R.N.
1955: Map of the physiographic regions of Ungava–Labrador. Canadian Geographer, Volume 5, pages 9-16.

Drake, L.D.
1983: Ore plumes in till. Journal of Geology, Volume 19, pages 707-713.

Dreimanis, A.
1956: Steep rock iron ore boulder train. Geological Association of Canada, Proceedings 8, Volume 1, pages 27-70.

1976: Tills: their origin and properties. *In* Glacial Till. *Edited by* R.F. Legget. Royal Society of Canada, Special Publication 12, pages 11-49.

1982: Work group (1)–Genetic classifications of tills and criteria for their differentiation: Progress report on activities 1977-1982, and definitions on glacigenic terms. *In* Schluchter Ch. (Editor). INQUA commission on genesis and lithology of Quaternary deposits, Report on Activities 1977-1982. ETH, Zurich, pages 12-31.

Dreimanis, A. and Vagners, U.J.
1971: Bimodal distribution of rock and mineral fragments in basal tills. *In* Till: A Symposium. *Edited by* R.P. Goldthwait. Ohio State University Press, Columbus, pages 237-250.

Drewry, D.
1986: Glacial geologic processes. Edward Arnold, London, 276 pages.

Dyke, A.S. and Prest, V.K.
1987: Late Wisconsinan and Holocene history of the Laurentide ice sheet. Géographie Physique et Quaternaire, Volume XLI, pages 237-264.

Eyles, N. (Editor)
1983: Glacial geology. An introduction for engineers and earth scientists. Pergamon Press, Oxford, 409 pages.

Flint, R.F.
1971: Glacial and Quaternary geology. Wiley and Sons, New York, 892 pages.

French, H.M.
1976: The periglacial environment. Longman, New York, 309 pages.

Geddes, R.S.
1982: The Vixen Lake indicator train, northern Saskatchewan. *In* Prospecting in Areas of Glaciated Terrain. *Edited by* P.H. Davenport. Canadian Institute of Mining and Metallurgy, St. John's, Newfoundland, pages 264-283.

Geological Survey of Canada
1986: Airborne Spectrometry. NTS 14D/5. Geophysical Series, Map 35414(5).

Grip, E.
1953: Tracing of glacial boulders as an aid to ore prospecting in Sweden. Economic Geology, Volume 48, pages 715-725.

Haldorsen, S.
1981: Grain-size distribution of subglacial till and its relation to glacial crushing and abrasion. Boreas, Volume 10, pages 91-105.

1983: Mineralogy and geochemistry of basal till and their relationship to till-forming processes. Norsk Geologisk Tidsskrift, Volume 1, pages 15-25.

Hawkes, H.E. and Webb, J.S.
1962: Geochemistry in mineral exploration. Harper and Row, New York, 415 pages.

Hillaire-Marcel, C., Grant, D.R. and Vincent, J.S.
1980: Comment and Reply on 'Keewatin Ice Sheet – Re-evaluation of the traditional concept of the Laurentide Ice Sheet' and 'Glacial erosion and ice sheet divides, northeastern Laurentide Ice Sheet, on the basis of the distribution of limestone erratics'. Geology, Volume 8, pages 466-471.

Hillefors, A.
1973: The stratigraphy and genesis of stoss- and lee-side moraines. Bulletin of the Geological Institute of the University of Uppsala, Volume 5, pages 139-154.

Hlava, M. and Krishnan, T.K.
1980: A report on the geological, geophysical and geochemcial assessment work, Strange Lake area, Newfoundland-Labrador, N.T.S Sheet 24A/8. Unpublished Report, Iron Ore Company of Canada. [LAB (560)]

Holmes, G.W.
1966: Early discoveries XXV. Stephen Reed, M.D., and the 'celebrated' Richmond boulder train of Berkshire County. Massachusetts, U.S.A. Journal of Glaciology, Volume 6, pages 431-437.

Hornbrook, E.H.W., Davenport, P.H. and Grant, D.R.
1975: Regional and detailed geochemical exploration studies in glaciated terrain in Newfoundland. Mineral Development Division, Department of Mines and Energy, Report 75-2, 116 pages.

Hyvarinen, L., Kauranne, K. and Yletyinen, V.
1973: Modern boulder tracing in prospecting. *In* Prospecting in Areas of Glacial Terrain. *Edited by* M.J. Jones. Institution of Mining and Metallurgy, Trondheim, Norway.

Ives, J.D.
1957: Glaciation of the Torngat Mountains, northern Labrador. Arctic, Volume 10, pages 67-87.

1960a: Former ice-dammed lake and the deglaciation of the middle reaches of the George River, Labrador-Ungava. Geographical Bulletin, Volume 14, pages 44-70.

1960b: The deglaciation of Labrador-Ungava: an outline. Cahiers de Geographie, Quebec, Volume 4, pages 323-343.

1978: The maximum extent of the Laurentide Ice Sheet along the east coast of North America during the last glaciation. Arctic, Volume 31, pages 24-53.

Ives, J.D., Nichols, H. and Short, S.
1976: Glacial history of Palaeoecology of Northeastern Nouveau-Quebec and Northern Labrador. Arctic, Volume 29, pages 48-52.

Jackson, L.
1986: World's largest caribou herd continues to grow. Canadian Geographic. October/November, 1986, pages 84-85.

John, B.S. (Editor)
1979: The winters of the world. David and Charles, London, 256 pages.

Klassen, R.A.
1984: A preliminary report on drift prospecting studies in Labrador, Part II. *In* Current Research. Part A, Geological Survey of Canada, Paper 84-1A, pages 90-97.

Klassen, R.A. and Shilts, W.W.
1977: Glacial dispersal of uranium in the District of Keewatin, Canada. *In* Prospecting in Areas on Glaciated Terrain. Institute of Mining and Metallurgy, Helsinki, Finland, pages 80-88.

Krüger, J.
1979: Structures and textures in till indicating subglacial deposition. Boreas, Volume 8, pages 323-340.

Lamb, H.F.
1980: Late Quaternary vegetational history of southeastern Labrador. Arctic and Alpine Research, Volume 12, pages 117-135.

Lawson, D.E.
1981: Distinguishing characteristics of diamictons at the margin of the Matanuska Glacier, Alaska. Annals of Glaciology, Volume 2, pages 78-84.

Lee, H.A.
1965: Investigation of eskers for mineral exploration. Geological Survey of Canada, Paper 65-14, 17 pages.

1968: An Ontario kimberlite occurrence discovered by application of the glaciofocus method to a study of the Munro Esker. Geological Survey of Canada, Paper 68-7, 3 pages.

Levinson, A.A.
1974: Introduction to exploration geochemistry. Applied Publishing Limited, Calgary, 612 pages.

Lopoukhine, N., Prout, N.A. and Hirvonen, H.E.
1977: Ecological land classification of Labrador: A reconnasissance. Ecological Land Classification Series, Number 4, Fisheries and Environment Canada, Halifax, Nova Scotia, 85 pages.

Macpherson, J.B.
1981: The development of the vegetation of Newfoundland and climatic change during the Holocene. *In* The Natural Environment of Newfoundland: Past and Present. *Edited by* A.G. Macpherson and J.B. Macpherson. Department of Geography, Memorial University of Newfoundland, pages 189-217.

McConnell, J.W. and Batterson, M.J.
1987: The Strange Lake Zr-Y-Nb-Be-REE Deposit, Labrador: A geochemical profile in till, lake and stream sediment and water. Journal of Geochemical Exploration, Volume 29, pages 105-127.

McConnell, J.W., Vanderveer, D.G., Batterson, M.J. and Davenport, P.H.
1984: Geochemical orientation studies and Quaternary mapping around the Strange Lake deposit, northern Labrador. *In* Current Research. Department of Mines and Energy, Mineral Development Division, Report 84-1, pages 98-102.

Miller, J.K
1984: Model for clastic indicator train in till. *In* Prospecting in Areas of Glaciated Terrain, 1984. Institute of Mining and Metallurgy, London, pages 69-78.

Miller, R.R.
1986: Geology of the Strange Lake Alkalic Complex and the associated Zr-Y-Nb-Be-REE mineralization. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 11-20.

Minell, H.
1978: Glaciological interpretations of boulder trains for the purpose of prospecting in till. Sveriges Geologiska Undersökning, Serie C. Nr 743, Stockholm, 51 pages.

Nie, M.H., Hull, C.H., Jenkins, J.G., Steinbrenner, K. and Bent, D.H.
1975: SPSS. Statistical package for the social sciences. Second Edition. McGraw-Hill, 675 pages.

Nilsson, G.
1973: Nickel prospecting and the discovery of the Mjovattnet mineralization, northern Sweden: a case history of the use of combined techniques in drift-covered glaciated terrain. *In* Prospecting in areas of glacial terrain. *Edited by* M.J. Jones. Institute of Mining and Metallurgy, Trondheim, Norway, pages 97-110.

Peach, J.A.
1975: The tourism and outdoor recreation climate of Newfoundland and Labrador. Atmospheric Environment Service, Environment Canada, Project Report Number 2a.

Prest, V.K., Grant, D.R. and Rampton, V.N.
1968: Glacial Map of Canada, 1:5,000,000 scale. Geological Survey of Canada, Map 1253A.

Ricketts, M.J.
1987: Aggregate-resource assessments along possible transportation routes from Strange Lake to the Atlantic coast, Labrador. Mineral Resource Report 4, Mineral Development Division, Newfoundland Department of Mines, 24 pages.

Ricketts, M.J. and Hayes, J.P.
1985: Aggregate resource inventory along possible routes from Strange Lake, Labrador to the Atlantic coast. *In* Current Research. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 85-1, pages 11-16.

Rowe, J.S.
1972: Forest regions of Canada. Department of Environment, Canadian Forestry Service, Publication 1300.

Ryan, B., Lee, D. and Dunphy, D.
1988: The discovery of probable Archean rocks within the Labrador arm of the Trans Hudson Orogen near the Labrador-Quebec border (NTS 14D/3, 4, 5 and 24A/1,8). *In* Current Reseach. Mineral Development Division, Newfoundland Department of Mines, Report 88-1, pages 1-14.

Shilts, W.W.
1972: Drift prospecting; geochemistry of eskers and till in permanently frozen terrain: District of Keewatin, Northwest Territories. Geological Survey of Canada, Paper 72-45, 34 pages.

1974: Physical and chemical properties of unconsolidated sediments in permanently frozen terrain, District of Keewatin, Geological Survey of Canada, Paper 74-1, Part A, pages 229-235.

1975: Principles of geochemical exploration for sulphide deposits using shallow samples of glacial drift. Canadian Institute of Mining and Metallurgy Bulletin, Volume 68, pages 73-80.

1976: Glacial till and mineral exploration. *In* Glacial till: An inter-disciplinary study. *Edited by* R.F. Legget. Royal Society of Canada, Special Publication Number 17, pages 205-224.

1978: Nature and genesis of mudboils, central Keewatin, Canada. Canadian Journal of Earth Sciences, Volume 15, pages 1053-1068.

1980: Flow patterns in the central North American ice sheet. Nature, Volume 286, pages 213-218.

1982: Glacial dispersal: principles and practical applications. Geoscience Canada, Volume 9, pages 42-48.

Shilts, W.W., Cunningham, C.M. and Kaszycki, C.A.
1979: Keewatin ice sheet—re-evaluation of the traditional concept of the Laurentide ice sheet. Geology, Volume 7, pages 537-541.

Sinclair, A.J.
1974: Selection of threshold values in geochemical data using probability graphs. Journal of Geochemical Exploration, Volume 3, pages 129-149.

Short, S.K.
1978: Palynology: A Holocene environmental perspective for archaeology in Labrador-Ungava. Arctic Anthropology, Volume 15, pages 9-35.

Sugden, D.E. and John, B.S.
1976: Glaciers and landscape. Edward Arnold, London, 376 pages.

Taylor, F.C.
1970: Reconnaissance geology of a part of the Precambrian shield, northwestern Quebec and northern Labrador, Part II. Geological Survey of Canada, Paper 70-24, 10 pages.

1979: Reconnaissance geology of a part of the Precambrian shield, northeastern Quebec, northern Labrador and Northwest Territories. Geological Survey of Canada, Memoir 393, 99 pages.

Thompson, F.J. and Klassen, R.A.
1986: Ice flow directions and drift composition, central Labrador. *In* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, pages 713-717.

Venkateswaran, G.P.
1983: A report on the geological, geophysical and geochemical assessment work; Strange Lake Area, Labrador. Iron Ore Company of Canada Report, November 1983, 25 pages. [24A/8 (7)]

Washburn, A.L.
1973: Periglacial processes and environments. Edward Arnold, London, 320 pages.

Zajac, I.S., Miller, R., Birkett, T. and Mantel, S.
1984: The Strange Lake deposit, Quebec-Labrador. Paper presented at the Canadian Institute of Mining Annual Meeting, Ottawa, April 16, 1984, 9 pages.